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# THE ADVANCED WASTE TREATMENT RESEARCH PROGRAM, JUNE 1960-DECEMBER 1961

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

May 1962

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# SUMMARY REPORT

## THE ADVANCED WASTE TREATMENT RESEARCH PROGRAM

June 1960 - December 1961

An activity of the Research Branch,
Division of Water Supply and Pollution Control

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

May 1962

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# FOREWORD

The Advanced Waste Treatment Research Program of the Public Health Service has two ultimate objectives. One is to alleviate our Nation's growing water pollution problem and the other, more startling in concept, is to renovate waste water for direct and deliberate reuse.

Our waste waters are right at hand. They do not have to be pumped long distances, over mountains, or from deep underground aquifers. To restore them for reuse requires processes suitable for removal of contaminants at a cost consistent with the value obtained. Conventional treatment processes, and we must include natural purification in our rivers and streams, are not capable of reducing the concentration of many water-borne contaminants to the levels required for many of today's water uses. Needed is a new technology for achieving highly efficient, yet economical, removal of these contaminants. The development of such an advanced waste treatment technology is the first objective of the Program - an objective of utmost importance to our future water resource. The second objective goes hand in hand with the first, for such a technology would purify waste water to such a degree that reuse for any purpose would be possible.

In the United States in the past several years a tremendous upsurge in public interest and professional concern has occurred regarding the adequacy and quality of our water resource. The National Water Pollution Conference held in December 1960, built on the theme "Clean Water - A Challenge to the Nation," focused attention on the many problems. The Senate Select Committee on Water Resources in its recently completed study of the Nation's requirements for water to serve our expanding population, agriculture, and industry to 1980, gave special attention to the need for protecting water quality to permit repeated reuse. In his February 23, 1961, message to Congress on natural resources, President Kennedy said:

> "Pollution of our country's rivers and streams has - as a result of our rapid population and industrial growth and change - reached alarming proportions. To meet all needs - domestic, agricultural, industrial, recreational - we shall have to use and reuse the same water, maintaining quality as well as quantity. In many areas we need new sources of supply - but in all areas we must protect the supplies we have."

One fact is clear, we are already reusing our water; 40 percent of the United States' population is using water that has been used at least once for domestic or industrial purposes. This natural reuse will increase. Another fact that is equally clear is that, without improved purification of waste water, intensified reuse will inevitably overtax the capacity of streams and water treatment plants to remove damaging contaminants. Indeed, such capacity has already been exceeded in some locations as evidenced

by foams, fish kills, foul-tasting water, and impairment to municipal and industrial water treatment processes.

Our task then is to do a better job in removal of contaminants from waste waters and, by so doing, renovate the water. The renovated supply can then be reused - even recycled.

The problems of water reuse have received some attention but only moderate study over the years. The concepts of the Advanced Waste Treatment Research Program were given in a paper presented in May 1959 at Purdue University by Gordon E. McCallum, Chief of the Public Health Service's Division of Water Supply and Pollution Control. The Program, embracing both extramural and intramural research, was implemented at the Robert A. Taft Sanitary Engineering Center In July 1960. Specific authorization for the Program was obtained with the passage in July 1961 of the amendments to the Federal Water Pollution Control Act (Public Law 87-88), which directed the Secretary of Health, Education, and Welfare "...to develop and demonstrate practicable means of treating municipal sewage and other water-borne wastes to remove the maximum possible amounts of physical, chemical, and biological pollutants in order to restore and maintain the maximum amount of the Nation's water at a quality suitable for repeated reuse."

This summary report covers the period from July 1960 through December 1961 and describes the Advanced Waste Treatment Research Program in five sections. The first section discusses the contaminants of challenge; the second the economic challenge; the third the technical approaches being explored; the fourth the organization and administration of the Program; and the fifth the present status of both extramural and intramural research efforts. This is the first in a series of reports. Other summary reports will be published from time to time, and detailed reports on selected research studies will be published as work is completed.



GPO 819664-2

# THE ADVANCED WASTE TREATMENT RESEARCH PROGRAM

## THE CONTAMINANTS OF CHALLENGE

Discussed below are the contaminants of challenge to advanced waste treatment processes and the damages to water quality that result from their presence in our lakes, our rivers, and our tap waters. The contaminants discussed are those resistant to or even totally unaffected by today's best conventional water and waste treatment processes, i. e., refractory contaminants.

## DAMAGES BY REFRACTORY SUBSTANCES

Evidence of the presence of refractory materials in water is manifested in a variety of damages that can be observed by the consumer of the drinking water, by the municipal or industrial user of the water, or by the conservationist and sportsman.

### Aesthetic Effects

Unpleasant tastes and odors in drinking water result from a variety of refractory materials and remain one of the principal problems in water purfication. The incidence of taste and odor episodes is a matter of increasing concern in many areas in this country. Consumers dislike such water and voice vigorous complaints to public officials, who, many times, are powerless to improve the situation. Off-tastes may also be caused in commercial food or drink products if the raw water used contains taste- and odor-bearing materials. Off-tastes in fish flesh are not uncommon in fish living in a polluted aquatic environment. Foaming at sewage treatment plants is unwelcome to neighbors and is a hazard to plant personnel. Foaming can also occur in streams and rivers; cases of foaming tap water have been reported. It is also obvious that objectionable odors and unsightly appearance in our water ways are aesthetically unpleasant. When these conditions interfere with recreational use of the water, a very real problem is created.

### Economic Effects

Refractory contaminants that cause corrosion or scale may have severe economic impact on a community. Pipes and fittings of a water distribution system may require maintenance or replacement at a prohibitive rate, for example. Although it is not proposed that municipal waste waters should receive treatment making them completely suitable for the most demanding technological uses (the water quality requirements for a high-pressure

boiler, for example, are much higher than for normal municipal use), it is expected that safe, palatable, generally non-corrosive and non-scaling waters should be provided by the municipality.

Some refractory materials in water can cause much-accelerated deterioration of ion-exchange resins; other materials are so toxic to biologic organisms that they cannot be tolerated in sewage treatment plants lest the biological treatment system be completely disrupted. Still other contaminants adversely affect coagulation and sedimentation rates in water treatment plants, inhibit oxygen transfer and oxidative reactions in waste treatment systems, or necessitate the application of larger and larger amounts of treatment chemicals. All are economic burdens imposed by the presence of refractory materials in our water. In the home, the need for using excessive quantities of soaps, detergents, and softening agents can add significant sums to the individual citizen's cost of living.

### Physiological Effects

Many materials are known to restrict growth or cause the death of fish and other aquatic life. In a growing number of cases, however, fish kills occur in which the guilty contaminant cannot be detected or identified. Such effects can result from the presence of astonishingly low concentrations of a toxicant--even 1 or 2 parts per billion of some chemicals can be lethal to certain sensitive fish. Other refractory contaminants can stimulate over-growths of organisms or algae--also an undesirable situation.

No adverse effects on human health attributable to the presence of refractory contaminants in this Nation's tap waters have been reported. Yet, trace quantities of many chemical, biological, and radiological pollutants are being detected in these waters in many areas. Although it is not known that their presence is harmful, it is also not known that their presence is safe. Toxicologist Dr. John A. Zapp, of the Haskell Laboratories of the DuPont Company, in referring to the contaminants in water has said, "It is a different kind of question about wholesomeness than that which has been asked heretofore. We know that the ingestion of these waters produces no immediate harmful effects. But what of the long run? What about 20 or 30 years from now? Will the continued ingestion of these waters over the years leave some cumulative effects which eventually produce disaster? The horizon of our concern has been pushed further into the future in these last decades."

## INORGANIC REFRACTORY MATERIALS

What inorganic ions that remain in the water after treatment are of concern?

The mineral quality of a sewage largely depends on the mineral quality of the water supply for the municipality but, during use of the water by the community, numerous substances are added. Many of these materials are simply additions of substances already present in the water supply; e. g., sodium chloride. Other

materials are added that are not common to the water supply or are found in natural waters in only trace amounts. Phosphates occur in low concentrations in most natural waters, but the increment from domestic use, principally from synthetic detergents, may be substantial. This has doubled in the past several years. Table 1 shows the increments of the common ions that result from one cycle of water use.

Table 1. Summary of Increments of Common Ions in Domestic Water After One Cycle of Water Use[a]

| Analysis | Parts per million | | |
|---|---|---|---|
| | Minimum increment | Maximum increment | Normal range |
| $Ca^{++}(CaCO_3)$ | -- | 250 | 15- 40 |
| $Mg^{++}(CaCO_3)$ | -- | 118 | 15- 40 |
| $Na^{+}$ | 30 | 290 | 40- 70 |
| $K^{+}$ | -- | 22 | 7- 15 |
| $SO_4^{=}$ | 0 | 75 | 15- 30 |
| $PO_4$[b] | 2 | 40 | 20- 40 |
| $Cl^{-}$ | 20 | 550 | 20- 50 |
| $NO_3$[c] | 0 | 18 | 0- 18 |
| Total (N) | 12 | 42 | 20- 40 |
| Total Alk ($CaCO_3$) | -- | 230 | 100-150 |
| Total Dissolved Solids | Trace | 1200 | 100-300 |

[a]Data from "Studies of Waste Water Reclamation and Utilization. State Water Pollution Control Board, Sacramento, California. Publication No. 9 (1954).

[b]Very low concentrations in natural waters.

[c]Results from biological action on organic nitrogen.

Sewage treatment plants receive a wide variety of industrial materials. Salts of chromium, copper, nickel, and other metals may enter waste waters in varying amounts and may exhibit varying degrees of resistance to treatment. The Public Health Service Drinking Water Standards[1] limit chromium to 0.05 mg/l. Moore et al.,[2] showed that hexavalent chromium up to 0.5 mg/l was almost completely removed by activated sludge treatment; 2 mg/l in the feed produced occasional chromium in the effluent, and with concentrations of 5 mg/l or more treatment was even less effective. At dosages of 50 mg/l more than 50 percent of the chromium was found in the effluent. Boron is of importance if the water is to be used for irrigation. Concentrations of 0.5 to 5 mg/l may harm plants. Some natural waters contain boron, and the material may occur in some wastes. The concentrations of common ions that are refractory to treatment and the difficulties they may cause are shown in Table 2. The data in this table are examples, not an exhaustive list of damages.

Common salt is refractory to ordinary waste purification and water treatment practices. A single water use causes an incremental increase in salt concentration. As reuse occurs, the salt content may increase to an objectionable level. Public Health Service Drinking Water Standards set 250 mg/l of chloride as a recommended maximum limit. Corrosion effects of salt are well known. Hence salt build-up through water reuse can occur, limiting the number of reuse cycles. A salt build-up of 25 to 100 mg/l

for each municipal use of water, is common; the amount of build-up, however, varies widely.

Table 2. Concentrations of Inorganic Refractory Ions Causing Damage

| Ion | Maximum allowable concentration, ppm[a] | Effect | Concentration causing effect, ppm |
|---|---|---|---|
| Cations | | | |
| Calcium | - | Adds hardness. | Over 100 (as $CaCO_3$) undesirable for municipal use. |
| Magnesium | - | Same as calcium. | Over 100 (as $CaCO_3$) |
| | | Cathartic. | 1000-2000(as $MgSO_4$) |
| Sodium | - | Physiological effect on persons with cardiac, renal or circulatory disease. | 200 |
| | | Foaming in boilers | 50 |
| Potassium | - | Cathartic. | 1000 - 2000 |
| | | Foaming in boilers. | 50 |
| Ammonia | - | Requires excess chlorine at water plant. | Any amount. |
| | | Toxic to fish. | 2.5 |
| | | Source of nitrates. | Any amount. |
| Anions | | | |
| Bicarbonate | - | Contributes to salinity and solids. | Over 200 undesirable |
| | | Hardness if as $Ca(HCO_3)_2$ | Over 100 undesirable |
| Chloride | 250 | Salty taste. | 250 |
| | | Interferes with industrial processes. | 75 - 200 |
| Sulfate | 250 | Cathartic. | 600 - 1000 |
| Nitrate | 45 | Nutrient stimulating undesirable aquatic growth. | 0.3 |
| | | Methemoglobinemia in infants. | 15 - 200 (a) |
| Phosphate | - | Nutrient stimulating undesirable aquatic growth. | 0.015 |

[a]Public Health Service Recommended Drinking Water Standards, 1961, Reference 1.

Nitrogeneous compounds appear as refractory materials at various stages of waste treatment and water purification. At the sewage treatment plant, nitrogeneous materials go through the familiar nitrogen cycle, producing ammonia, nitrites, and nitrates.

Ammonia appears in even the best-oxidized effluents, including those from the activated sludge process. In additon to the ammonia formed by the treatment, large quantities are returned to the process from the digester supernatant. Once in the stream, ammonia may be toxic to fish. Oxidation of ammonia to nitrates continues in the stream, but free ammonia may persist in cold weather. Excessive amounts of chlorine are required if the water is treated by break-point chlorination at the water plant. Ammonia is an undesirable constituent in industrial cooling waters because of corrosive effects on some metals. Ammonia is not ordinarily a problem in drinking waters and may be added along with chlorine as a final treatment step to maintain a chloramine residual.

Nitrites, the next products of oxidation beyond ammonia, are usually short-lived and soon are oxidized to nitrates. Only slight concentrations of these compounds persist in surface waters. Because large concentrations of nitrites may have physiological effects, care should be taken not to introduce them into water supplies inadvertently as anticorrosion agents.

The end products of aerobic stabilization of organic nitrogen are nitrates. Although the net effect of sewage treatment is to reduce the nitrogen content, the increment of nitrates through treat-

ment may be as much as 18 or 20 mg/l in well-oxidized effluents. Nitrates may also enter water in fertilizers that wash into the stream. Nitrates are very stable and are of interest because, like other nutrients such as phosphates, they may cause rapid blooms of organisms when discharged to rivers. If effluents are to be used for irrigation, however, the nitrates are desirable.

Nitrates in concentrations of 15 to 250 mg/l in water have been shown to be responsible for methemoglobinemia in infants.[3] Other factors that are little understood, including the presence of nitrites, may influence the toxic reaction to nitrates. Methemoglobinemia has been associated with the use of water from private wells (usually farm wells) rather than with public water supplies derived from surface waters. The Public Health Service Drinking Water Standards indicate a maximum limit for nitrate ion of 45 mg/l (or 10 mg/l $NO_3$-N).

A method for reduction of nitrates in the activated sludge treatment plant effluent has recently been proposed by Ludzack and Ettinger.[4] The process is based on starving the organisms for oxygen at one stage of treatment, thus using them to use the $NO_3$ as the oxygen source; thus, the $NO_3$ is reduced to nitrogen gas.

Table 3 shows the effectiveness of sewage purification, natural purification, and water treatment on the common inorganic ions found in waters and waste waters. Information is sparse on most of the uncommon ions.

Table 3. Effectiveness of Sewage Treatment, Natural Purification, and Water Treatment on Removal of Common Inorganic Ions

| Common inorganic refractory ions | Effectiveness of removal | | |
|---|---|---|---|
| | Secondary sewage treatment | Natural purification | Water treatment |
| Cations | | | |
| Calcium | Little or none. | Little or none. | Removed--if water is softened. |
| Magnesium | Little or none. | Little or none. | Removed--if water is softened. |
| Sodium | None. | None. | None. |
| Potassium | None. | None. | None. |
| Ammonia | Builds up during nitrogen decomposition. Partial removal by oxidation to nitrates. | Slowly changes to nitrate. | May be oxidized by chlorine or caused to form chloramine. |
| Anions | | | |
| Bicarbonate | Little or none. Builds up in digester. | Little or none. | Removed--if present in Ca or Mg form and softened. |
| Chloride | None. | None. | None. |
| Sulfate | Little or none. | Little or none. | Removed--if water is softened. |
| Nitrate | Treatment usually increases nitrates. | Used by plant life in growth. | None. |
| Phosphate | Partial (80-90%). | Partial removal by utilization by plants. | Little or none. |

## ORGANIC REFRACTORY MATERIALS

The modern sewage treatment plant is designed to permit settling of the bulk of organic and inorganic insoluble solids. These solids are disposed of separately. Often this primary treatment is all that is provided. Primary treatment removes only 30 or 40 percent of the biochemical-oxygen-demanding materials and does nothing to the more resistant substances. Secondary treatment involves the application of a biological process to the primary effluent. Activated sludge and trickling filters are the most common secondary treatment processes. In the secondary process, suspended and dissolved organic materials that can be attacked by organisms are partially or completely destroyed. Usually 80 to 90 percent of the oxygen demand, as measured by the biochemical oxygen demand (BOD) test, will be satisfied. Although under proper conditions and with sufficient time, all organic materials may be degraded by appropriate organisms, complete degradation does not occur on a practical basis and residual or refractory materials remain in the effluents. Ludzack[5] has discussed the effect of aerobic oxidation on a large number of organic substances. High-molecular-weight materials and tertiary-branched structures are usually resistant to aerobic purification. When carbon is replaced in a chain by oxygen, sulfur, or nitrogen, the compounds are more resistant to degradation; however, many exceptions occur. Sewage treatment deals with very large volumes. McCallum,[6] in a report on the build-up of chemicals at Chicago, points out that the BOD remaining in the effluent of Chicago sewage amounts to 100 tons per day. The portion of the non-BOD organic matter remaining after treatment added an additional 1000 tons per day.

Table 4. Soluble Organic Constituents Refractory to Secondary Sewage Treatment[a]

| Component | % of total COD | Remarks |
|---|---|---|
| Ether extractables | <10 | 63% organic acids; 27% neutral materials; and 9% other classes. |
| Proteins | <10 | |
| Carbohydrates and polysaccharides | <5 | No simple sugars |
| Tannins and lignins | <5 | |
| Alkylbenzenesulfonate | ≥10 | |
| Unidentified | ≥65 | |

[a]Reference 7.

Some suspended solids escape from even our best processes; however, such materials can be removed. Our concern is with the dissolved substances that resist treatment. Bunch[7] analyzed fil-

tered effluents from secondary treatment plants to determine the classes of compounds. The chemical oxygen demand (COD) of these compounds was compared to the COD exhibited by the total effluent. Table 4 shows the results of these tests. The COD test is a measure of the oxygen required to oxidize those compounds that will be attacked by a dichromate solution in sulfuric acid. The COD test is an indirect measure of total organic contamination. Tap waters are very low in COD. Treated effluents may range from a few parts per million to several hundred parts per million.

Alkylbenzenesulfonate (ABS) is the only raw sewage component that is clearly recognizable in these tests. The other residues may be present in raw sewage, or may represent partially oxidized fragments of original organics, or metabolic products of the biological action in the treatment. We do not know the composition of 65 percent of these components. More exhaustive studies are underway to identify them.

ABS is an example of a compound that partially resists our best sewage treatment, and it demonstrates how our developing technology changes the composition of our wastes. Twenty-five years ago household synthetic detergents were virtually unheard of; today four billion pounds are produced annually, all of which end up in waste waters.

In raw sewage the concentration of ABS, expressed as the surfactant itself, usually ranges from 5 to 10 mg/l. Conventional secondary sewage treatment may reduce this concentration as much as one-half.[8] Concentrations of 1 mg/l or more are likely to foam when agitated. Such concentrations of ABS would severely limit many reuse applications of effluents. If direct injection of effluent waters into underground aquifers for replenishment of underground supplies is contemplated, ABS would be unwelcome.

Organic acids are components that not only survive sewage treatment but also occur naturally. A wide variety of such acids may occur, ranging from acetic acid to the complex humic acids. The lower-molecular-weight acids in concentrations well below 1 mg/l can cause taste and odor in water. The more-complex acidic materials have been linked with unusual losses of capacity in ion-exchange materials.[9, 10] It is reasonable to expect damage from organic acids if water is reused several times.

Refractories in sewage effluents undergo changes when they enter surface streams. The location of the sewage outfall, dilution afforded, time of travel, and many other factors determine what effect, if any, the refractories have on the downstream water treatment plant or other water use. All wastes may not get to the treatment plant. Storm-water overflows carry contaminants. Hence, the river receives a pollutional load from these sources - frequently a substantial one.

Rivers are polluted not only by domestic wastes but also by treated and untreated industrial wastes, and by chemicals used in agriculture. The river serves as a treatment mechanism for the conglomerate of contaminants. Many chemicals, resist this natu-

ral purification, however, and reach the water plant intake. Because the water treatment processes are not always effective, the consumer sometimes receives refractories that survive all the forces that have been applied. For a chemical to reach the consumer through drinking water taken from surface supplies, it must have survived settling, biological oxidation, chemical oxidation, vaporization, adsorption onto silt, coagulation, filtration, and exposure to a chemical oxidant such as chlorine or chlorine dioxide. In some cases it must also resist adsorption onto activated carbon. Organic chemicals usually remain in only small concentrations; however, small concentrations can cause undesirable effects. Many organics at concentrations of less than 0.1 mg/l cause taste and odor. In one instance, orthonitrochlorobenzene (ONCB) discharged at St. Louis in a waste traveled 1000 miles in the Mississippi River and was detected at New Orleans. The chemical was unaffected by water treatment.

Should a chemical such as ONCB be permitted in drinking water? When notified of the presence of ONCB in the river and drinking water, the polluter voluntarily stopped discharging this waste to the river - at considerable cost. Although ONCB has toxic properties, the concentrations found in the water were 300- to 500-fold lower than a single toxic dose; however, because of unknown factors such as slug concentrations, possible cumulative effects, and perhaps the greater susceptibility of the very young or the very old, this chemical was removed from the waterway. Further research is needed on the possible physiological effects of low concentrations of such chemicals in water.

Table 5. Organic Chemicals Recovered from River and Drinking Waters

| Specifics | Classes |
|---|---|
| Synthetic detergents (ABS) | acids |
| Phenyl ether | esters |
| Phenol | ketones |
| DDT | mines |
| Aldrin | cohols |
| Orthonitrochlorobenzene | aldehydes |
| α Conedendrin | nitriles |
| Xylene | |

It is not practical to analyze waters on a routine basis for the wide variety of organic chemicals that may occur. Specialized procedures have revealed a variety of contaminants. Table 5 is a partial list of such contaminants. Because of known and potential damages from these compounds, however, carbon chloroform extract at a recommended limit of 200 micrograms per liter of drinking water has been included in the Public Health Service Drinking

Water Standards for 1961. Ettinger[11] explained the basis for setting the standard at this level; it can be considered as a shield against undue stress on a water caused by mixed organics of unknown origin, particularly industrial materials, insecticides, and synthetics.

## SUMMARY

It is clear that many of the inorganic and organic contaminants that enter water resist our present day conventional treatment processes - sewage treatment, natural purification in streams, and water treatment. These contaminants have various effects on the use of the water, and as its reuse inevitably increases, they will tend to build up, causing the water to deteriorate further in quality.

The presence of these contaminants calls for a new look at our water and waste treatment processes. Additional treatment is needed to separate the contaminants not now removed, or new processes must be found that will be capable of removing a larger portion of contaminants. Some of the possible ways of achieving these separations will be found in a subsequent section of this report.

# THE ECONOMIC CHALLENGE

Water tends to be valued by its production cost instead of its economic worth. Much has been written about the economic worth of water, and most people generally agree that water is, without question, one of our best bargains. In fact, being essential, it can be priceless. Often, however, people fail to consider all the factors that influence costs in water use.

There is however, a limit to the price we can pay for this "priceless" necessity. The limit is imposed by practical economics - we cannot afford to pay more for water use than the very minimum possible cost.

Our fresh water resources not only provide water for municipal use but serve also to dilute and transport our wastes. With an expanding population, both needs will be intensified. Even if all wastes were being given complete conventional treatment, our rivers and streams would reach their capacity for assimilating wastes at some point in the not too distant future. This condition has already been experienced at a number of locations. Also, even if these surface waters could be maintained at a quality permitting conversion to acceptable water supplies by means of conventional water treatment, their amount is fixed and we would reach a point in time at which there would be no more developable fresh water within our land boundaries. These facts were brought out quite clearly in the comprehensive report published in 1960 by the Senate Select Committee on Natural Resources.[12 13]

The basic solution to these problems must be found in a more efficient utilization of our existing water resources, through multiple reuse.

The economic analysis of water resource development projects is probably one of the most controversial subjects presently under consideration. The philosophies of water utilization and conservation are so numerous and so diverse that it is almost impossible to ferret out enough common factors to utilize as the basis for solution of practical problems. It is especially difficult to find agreement on cost and value concepts, and as a result, the significance of cost figures for proposed and even for existing water resource developments are highly disputable.

Because the economics of an advanced waste treatment system is the major criterion governing practical feasibility, development of reliable cost data is an essential responsibility of the AWTR Program. Such data must be obtained in order to provide a meaningful basis on which to evaluate research and developmental work. Unfortunately, specific cost information regarding advanced waste treatment processes is non-existent at this time. As a result, it seems desirable to obtain at least baseline information on cost goals by assessing the costs of existing water and of the waste treatment operations that an advanced waste treatment system would ultimately perform.



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Ideally, an analysis such as this should provide cost information in as much detail as possible. This goal, however, cannot be attained. In most cases detailed breakdowns of various water and waste treatment costs simply do not exist; often, even when data are available, true costs are obscured by unrealistic bookkeeping and non-uniformity in cost analysis procedures, not to mention the adjustment of costs upward or downward for accounting purposes.

Fortunately, information is available on average costs of various elements of today's water and sewage treatment technology. This information, based on data from national surveys such as those conducted by the Public Health Service, [14, 15] the U. S. Census Bureau, [16] the American Water Works Association, [17, 18] and the American Public Works Association, [19] provides the foundation for the analysis below. It is hoped that by utilizing these several extensive, broad, and independent surveys deviations from true average figures will be minimized.

It is recognized that cost goals for specific projects cannot be developed from national average costs. These figures will not give us projected advanced waste treatment costs nor will they resolve the question of which method of supply should be used. They are presented here only as a preliminary guide to our thinking on the economics of water renovation. It should also be understood that in an advanced waste treatment system it is possible to make maximum use of existing facilities without retiring valuable property. In some cases it may be more economical to completely replace an existing facility, but in most cases this is unlikely.

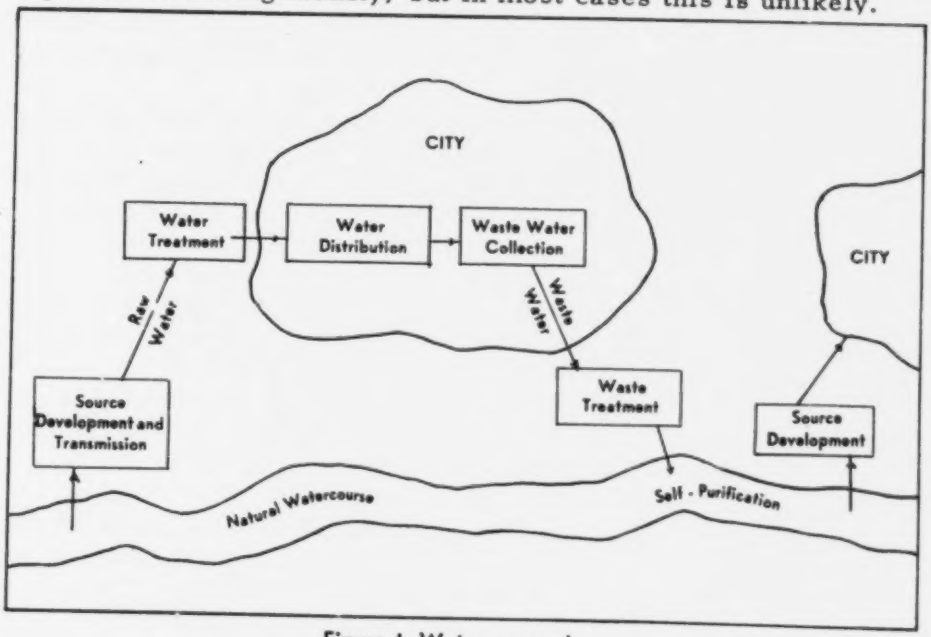


Figure 1. Water-use cycle

Water supply and waste treatment costs can be ascribed to the major elements of the typical municipal water-use cycle depicted in Figure 1. As shown, both water and sewage treatment must be

considered together in a realistic total water-use cycle. The first cost in the cycle is for development of the source and for transmission to the treatment plant. The average cost over the United States for these functions is about 5 cents per 1000 gallons. These costs range from 0 to about 30 cents per 1000 gallons, and prevailing high costs for development and transmission approach 22 cents per 1000 gallons. These figures, as do all those presented in this section, represent total costs, including operation and maintenance plus amortization of the original investment.

Treatment costs range between 0 and 9 cents per 1000 gallons. The national average is about 6 cents per 1000 gallons, with prevailing high costs perhaps a penny higher. Since treatment costs vary directly with the quality of the supply, any improved quality of our fresh water resources due to the introduction of advanced waste treatment processes would decrease the cost of water treatment in downstream communities, even those not employing advanced treatment systems.

Water distribution and waste collection constitute a major part of the water-use expense. Water distribution averages 17 cents per 1000 gallons, and waste collection averages about 6 cents per 1000 gallons over the United States. These costs, since water distribution and waste collection will always be necessary, would probably be unaffected by any advanced waste treatment system.

Following waste collection in the water-use cycle is sewage treatment and disposal. The average cost of these operations is 6 cents per 1000 gallons. They vary from 0 to 8 cents per 1000 gallons, with the prevailing high costs not significantly higher than the average.

It would be extremely unrealistic if we stopped our discussion of the cost of water use at this point. In addition to these obvious costs, other costs of today's water use should be considered. In areas where ground water is the conventional supply, lowering of the ground water table through pumping may increase pumping costs to all common users of that underground source. Water removal from conventional sources may deprive many users of a cheap water source, forcing use of more expensive water. Natural purification in our streams and lakes must logically be included as an element of waste treatment. Indeed, we design our treatment plants around the assimilative capacity of receiving waters. Although many of us do not like to accept the fact that natural treatment costs money, it does. Fish kills, game fish deterioration, and loss of recreational usefulness of the water are all expensive effects. Another of these indirect costs is the incremental cost imposed upon the downstream water user; this results from the necessity of removing the additional pollutants his upstream neighbor introduced.

The above are examples of indirect costs of our present water-use cycle, but each could be measured in terms of dollars. Other indirect effects cannot be quantitated in this way; they are, nevertheless, very real. How much, for example, is the value of water-

based recreation in non-polluted, aesthetically acceptable surroundings? Even more to the point, how much is the assurance worth that chemical, biological, or radiological pollutants are not exerting subtle, cumulative effects on the health of man?

If we do not consider the indirect costs of our present water-use systems, what would the cost of an advanced waste treatment system have to be to compete now with the conventional water supply and waste treatment?

As an estimated cost goal, we could say that since advanced waste treatment will accomplish the functions of source development, transmission, water treatment, waste treatment, and disposal the sum of their costs in today's technology might suggest a rough figure. The total is about 17 cents per 1000 gallons on a national average, and roughly 35 cents per 1000 gallons in prevailing high-cost areas of this country.

That complete advanced waste treatment costs would reach these goals is almost completely out of the question. A technology utilizing new and more-complex processes will undoubtedly be more expensive than our present methodology. The "law of diminishing returns" dictates however, that tomorrow's water will cost more and more, even if we continue to use today's methods.

Definitive cost goals have not been established for advanced waste treatment - it would be impossible to do this with our current knowledge. The only realistic cost goal that can ever be stated with certainty is that the cost of water renovation must be the very minimum that science and engineering can achieve - anything greater will impose an inexcusable and perhaps intolerable handicap on our country's economic growth.

Finally, it is appropriate to mention that advanced waste treatment is not competing for limited markets. Rather, it is the core of a new policy of water conservation. The purpose of a program in advanced waste treatment is not merely to provide additional drinking water and dilution for our existing wastes; its purpose is to spearhead a movement for the most efficient use of our most precious resource. How much can we afford to pay for it?

# TECHNICAL APPROACHES TO ADVANCED WASTE TREATMENT

Two important objectives must be achieved if the total concept of advanced waste treatment is to be feasible. First, it will be essential to concentrate the impurities in municipal waste water into small volumes and to dispose permanently of this concentrate. Second, it will be necessary to produce purified water of a quality suitable for direct reuse. To explain, concentrated wastes removed by advanced waste treatment processes cannot, of course, be returned to surface waters; if this were done, stream pollution problems would not be diminished and downstream water users would have to remove the same contaminants again and again. The development of methods for permanently disposing of concentrated impurities is, therefore, an important part of the concept. Furthermore, if contaminants in waste water are removed efficiently, it is evident that the purified water discharged will be of excellent quality. Such water, especially where concern over quantity and/or quality of water from conventional sources exists (and this will be true wherever advanced waste treatment is called for), must not be wasted. In most cases it would be folly, for example, to discharge such water into a stream less pure - perhaps very much less pure - than the discharge itself. The development of a successful advanced waste treatment technology, therefore, could lead - at one step - to the alleviation of both water pollution and water supply problems.

From a technical standpoint, advanced waste treatment may be looked upon as a two-step process: (1) separation of concentrated contaminants from the purified water "product," and (2) disposal of the concentrated contaminants in a way that renders them forever innocuous. Research is necessary, therefore, on both "separation" and "permanent disposal" techniques. These two elements of advanced waste treatment are related economically, since, in general, the further waste is concentrated, the higher the cost of concentration but the lower the cost of disposal. Obvious relationships to be developed for all technically feasible approaches are "cost vs. degree of concentration" for the separation processes and "cost vs. volume to be disposed of" for the permanent disposal methods.

At this point, it may be of interest to discuss briefly the technological differences between advanced waste treatment and saline water conversion. In spite of the seeming similarities, a number of important differences exist. First, there is the problem of permanent disposal of the concentrated wastes. Researchers on sea water conversion are not concerned with this problem. When a conversion plant is situated on the ocean's shore, concentrated waste brine can be dumped right back into the sea which serves as an infinite waste sink. In Kansas City or in Cincinnati, however,

there is no suitable place to "dump" the concentrated wastes from a water renovation plant. To be able to dispose permanently of the waste, therefore, advanced waste treatment researchers must strive for product-to-waste ratios much higher than those considered satisfactory for saline water conversion. Whereas a 1:1 ratio, i.e., one volume of product generates one volume of waste brine, is satisfactory for desalination; ratios of at least 100:1 and very possibly 1000:1 must be achieved in waste water renovation. Such a requirement makes one problem much different from the other, technically.

Second, the types of impurities of challenge in water-borne wastes are very different from those in saline waters. In waste waters there are obviously significant quantities of organic materials not found in large amounts in the sea. There may also appear a broad spectrum of industrial wastes as well as biological and even radio-active pollutants.

Third, the physical and chemical characters of the feed streams are distinctively different. Theoretically, the carrier fluids for both saline waters and waste waters are the same - $H_2O$. Practically, however, the feed streams are very different - one is salt water, the other fresh. This difference is reflected in the properties of the two streams, the viscosity, the thermal conductivity, the ohmic resistance, the freezing point depression and boiling point elevation, the corrosivity, etc., factors which can conceivably have a significant bearing on the technological feasibility, on the engineering process design, and, most important, on the economics of the various separation techniques under study.

Fourth, the water renovation problem is dynamic whereas the saline water problem is static. In any one location, for example, the feed composition to a desalination plant should remain essentially constant. It is not expected that the composition of the sea will change appreciably over the next 50 to 100 years. But in an advanced waste treatment plant, the process must be ready to accommodate a feed stream that is changing in composition and concentration continuously, from hour to hour. It also must accept changes from day to day, from season to season, and certainly long-term changes from year to year. To illustrate, 25 years ago no synthetic detergents were found in waste water - today they are. Today there are no soluble packaging materials present - but five years from today, it is anticipated that such materials will be a common component of our waste. Geographically too, feed composition will vary. More and more the compositon of a municipal waste stream reflects the make-up of the area's industrial complex.

Finally, the types of treatment processes that must be considered for purifying waste waters encompass not only those capable of purifying saline waters but also many others relying, in a number of cases, on entirely different principles of separation. This is true because of the dissimilar nature of both concentration and composition of impurities.

There are certain advantages associated with each of these two similar and yet basically different methods for producing potable water. For saline water conversion, a waste sink is available (at least for sea water conversion) into which concentrated brine may be discarded, feed composition is essentially constant, and no aesthetic barriers must be overcome. For waste water renovation the total load of contaminants to be removed is much lower and, thermodynamically at least, renovation should be cheaper than desalination, since a feed material is immediately "at hand" at every location at which water is being used and, of extreme importance, a water quality renovation unit could solve both problems of water supply and water pollution simultaneously.

## SEPARATION PROCESSES

It is conceivable that almost any physical or chemical principle of separation is applicable to advanced waste treatment. Even today, principles under active consideration include adsorption, electrodialysis, emulsion separation, evaporation, extraction, foaming, freezing, hydration, ion exchange, and chemical or electrochemical oxidation. It is recognized that these unit operations are foreign to the municipal waste treatment field and that they are unconventional by today's standards. Yet we are faced with an unconventional problem, one which will require broad, imaginative, perhaps unconventional thinking to solve.

In the following paragraphs some of the possible water renovation processes are reviewed. Because the attack on this problem is in its very earliest stage, (the first research project under the Advanced Waste Treatment Program was initiated just 1 year ago), this discussion can only touch on what may be possible, not on what will be possible - only research and experience can provide this information. Emphasis will be given to innovations that might overcome current limitations, making approaches that are not feasible today technically and economically feasible tomorrow.

### Adsorption

Probably the most likely contender for a position in the technology of advanced waste treatment is adsorption - the concentration and collection of contaminants at the surface of a solid. The solid or "adsorbent" can then be removed from the liquid by simple mechanical means, taking associated impurities along with it. Use of activated carbon adsorbents is a proven technique for removing water the same soluble organic contaminants that are refractory toward conventional water and waste treatment. Right now, tastes and odors are being removed from many water supplies by activated carbon. In this water treatment application the concentration of taste- and odor-causing contaminants is extremely low far below the concentrations of materials that must be eliminated in water renovation. Since an adsorbent can only collect a limited quantity of material before it becomes saturated, today's methods would

be economically impractical for advanced waste treatment, unless the adsorbents used were very inexpensive or could be economically regenerated to allow multiple reuse. Research interest, therefore, is both in low-cost adsorbents and in low-cost regeneration methods.

In the category of low-cost adsorbents are many naturally occurring materials such as clays, sands, coal, or other minerals, various industrial by-products, and even waste materials. Their application could be justified if their low cost would more than compensate for their less-attractive adsorptive qualities. Since adsorption is a surface phenomenon, adsorbents of low porosity, i.e., those with low internal surface, might be utilized in very finely divided form to expose large external surface. As particle size is decreased, however, the difficulty of separating the adsorbent itself from the liquid being treated increases. One possible solution involves the art and science of coagulation. Can this technique, perhaps with the utilization of new coagulant aids, be employed to allow economic removal of very fine adsorbents after liquid-solid contact in such devices as the "sludge blanket filter" (Figure 2)?

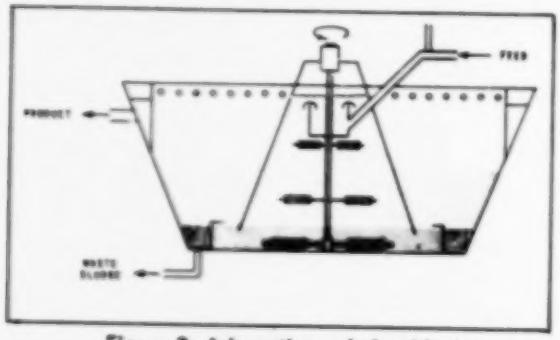

Figure 2. Adsorption - sludge blanket

The recovery of heat values from both adsorbent and adsorbed organic materials could improve the economics of large-scale adsorption. In other words, by use of an organic adsorbent such as pulverized coal, the spent adsorbent would not have to be regenerated but could be used as fuel. Thus, adsorbent charges would be limited to handling costs including, of course, necessary dewatering steps.

At the other end of the scale lie the high-quality, high-capacity, high-cost adsorbents. The many varieties of activated carbons and charcoals fall in this group, as would any synthetic adsorbents specifically tailored for advanced waste treatment purposes. Such substances would be practical only if regeneration and multiple reuse were possible. Granular regenerable activated carbon is used today with "thermal" regeneration - baking off adsorbed materials at high temperature, but it is not known as yet whether existing methods and equipment (Figure 3) can be economically applied to the complete renovation of municipal wastes. Other methods of regeneration, steaming, extraction, etc., must be

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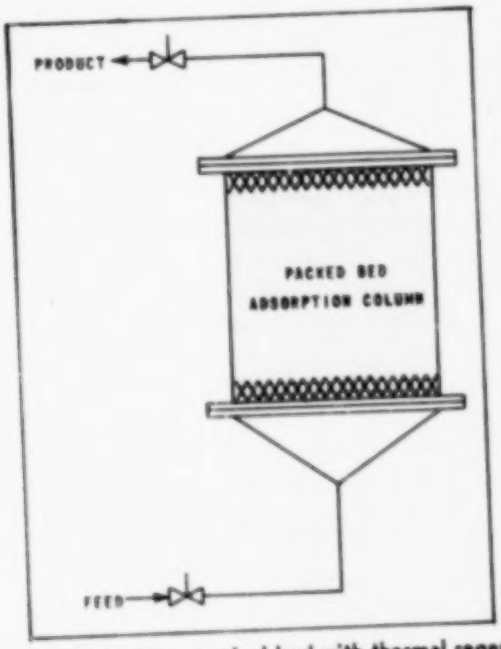


Figure 3. Adsorption - packed bed with thermal regeneration

evaluated. New techniques under consideration include selective oxidation of adsorbed materials in situ with oxidants such as ozone, hydrogen peroxide, etc., (Figure 4). One advanced waste treatment contractor has suggested that under the proper conditions two different adsorbents may be used in tandem to give better performance than would have been possible with either of the two adsorbents individually.[20] Also, methods for producing appreciably

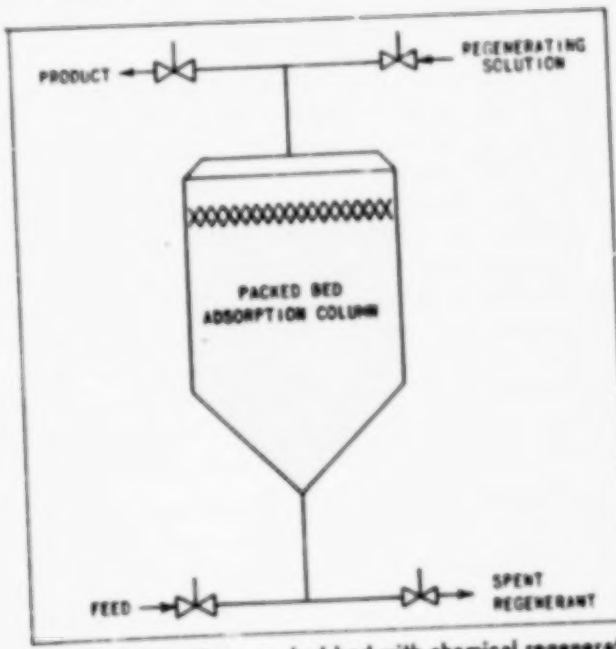


Figure 4. Adsorption - packed bed with chemical regeneration

cheaper activated carbons have been suggested. The techniques above may be important in achieving minimum costs. Several of them are already under study; additional work is planned.

## Electrodialysis

Electrodialysis is a fairly common laboratory technique for concentrating ionic materials in solution. To explain briefly, electrodes are used to impress an electrical field across a cell through which the liquid to be purified is flowing. This field causes cations (positive ions) to migrate toward the cathode, and anions (negative ions) toward the anode. If a number of alternately cation- and anion-permeable membranes are placed between the two electrodes, then both cations and anions can be removed from alternate compartments and concentrated in the intervening compartments. As shown in Figure 5, feed will enter a compartment, and the cations

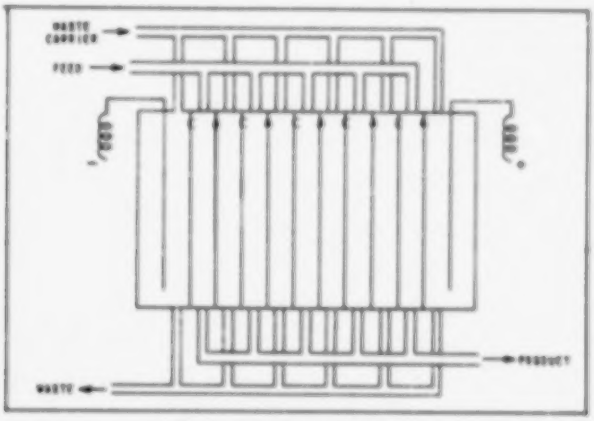

Figure 5. Electrodialysis

present, being attracted toward the cathode, will pass through a cation-permeable membrane into the adjacent compartment. The cation continues to migrate in the same direction but cannot leave that compartment because it next encounters an anion-permeable membrane. Hence, the cation stays in the compartment to be flushed out by a waste carrier stream. Similarly, anions contained in the feed will be caused to migrate in the opposite direction, toward the anode and through an anion-permeable membrane into the adjacent compartment from which they are removed by the waste carrier stream. Electrodialysis does not appear to offer economical conversion of waters containing high concentrations of ionic impurities, e.g., sea water, but is thought to offer appreciable promise for treatment of waters of lower ionic strength.

Electrodialytic purification of brackish waters is already an accomplished fact in a number of plants throughout the world; its potential for waste water renovation is only now being assessed. Several possible innovations to conventional electrodialysis are of interest. It has recently been demonstrated that it is possible to

recirculate a waste carrier stream continuously and to discharge essentially solid comtaminants from this stream by precipitation.[21] This can be done by operating on the carrier stream in such a way that it becomes supersaturated within the electrodialysis unit - that is, materials are prevented from precipitating out even though their solubilities have been exceeded - then inducing precipitation from supersaturated solution in some other part of the system. If this technique is used, it could offer great advantage. Damp salt would be discharged as the concentrated waste; this, of course, would provide a very high, very desirable product-to-waste ratio.

Another limitation to conventional electrodialysis is the sharply increasing power requirement necessary to reduce ionic concentrations further and further, below roughly 500-700 mg/l. Unfortunately, as electrolyte concentration goes down, the internal resistance of the purified liquid goes up, polarization increases, and energy losses become excessive. PHS Drinking Water Standards[1] recommend chloride concentrations below 250 mg/l and total dissolved solids concentrations below 500 mg/l; high-quality water could be expensive to achieve by current electrodialytic practice.

Possible methods are being investigated for overcoming this cost limitation. For example, packed beds of mixed ion exchange resin beads placed between cell membranes could effectively lower non-productive power consumption.[22] This method has certain practical disadvantages, however, and other techniques are under investigation. Another obvious area of interest is the synthesis of new membrane compositions capable of conducting even large organic ions such as are found in municipal waste streams. Furthermore, to make electrodialysis more generally effective for removal of both inorganic and organic contaminants, several methods have been considered for converting non-ionic organic molecules to ionic form.

## Evaporation

It is certain that aqueous waste streams can be purified by distillation. Experiments by Public Health Service researchers[7] have shown that the chemical oxygen demand (COD) of secondary sewage plant effluents can be reduced from feed to distillate by at least 98-99 percent in a simple, single-stage vacuum evaporation. It is equally certain, however, that single-stage vacuum evaporation cannot be accomplished economically for advanced waste treatment purposes. Through heat economization, however, evaporation, the process perhaps best suited to handle feeds containing complex and variable impurities, may well command a strong position in the economic competition for a place in water renovation.

There are several ways in which heat economy may be achieved. Multiple-effect evaporation (Figure 6), for example, is an old-line, classical chemical engineering approach to concentrating materials in solution. The principle is to supply, from one external boiler,

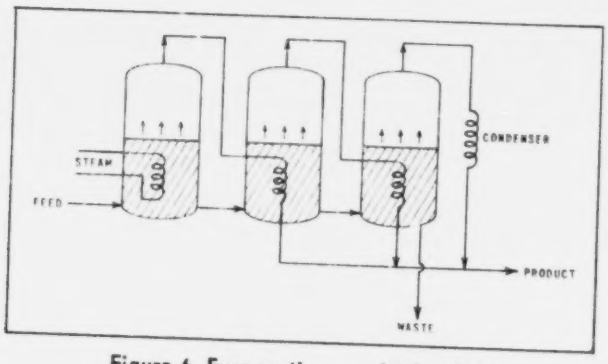


Figure 6. Evaporation - multiple-effect

steam that will condense in the heating coil of the "first effect." As each pound of steam condenses in the first effect, it gives up its latent heat of vaporization and causes essentially one more pound of water to evaporate. This pound of steam from the first effect now becomes the steam supply for the second effect. It subsequently condenses there, giving up its latent heat and thereby evaporating a second pound of water, this time at a slightly lower pressure. This steam, in turn, passes to the next effect, in which a third pound of water is evaporated, and so on. Four and six effects are common in the chemical industry; twelve-effect evaporators have been constructed for sea water conversion.

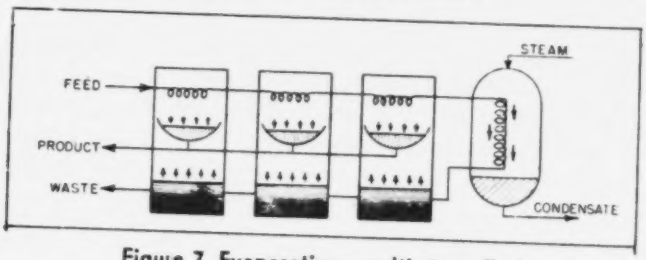


Figure 7. Evaporation - multi-stage flash

Multi-stage flash evaporation is another possibility (Figure 7). Water is flashed in a number of stages at successively lower temperatures. The latent heat of condensation released in each stage is used to preheat the feed, with externally generated steam being used only for a final temperature boost to the first stage. It has been calculated[23] that multi-stage flash or multiple-effect evaporators may produce distilled water from municipal waste waters for 8 to 9 cents per 1000 gallons less than from sea water. This is true primarily because of the larger number of stages or effects that may be possible when a much lower load of total impurities is present in the feed.

The vapor recompression still (Figure 8) is another technique for achieving heat economy. Instead of a number of stages in series, there is only one evaporator body to which preheated feed is introduced. The steam produced in this evaporator is compressed and fed right back into the heating coil of the evaporator. Because of the heat of compression, which raises the temperature

of the steam slightly, the steam is capable of driving its latent heat back through the heating coil into the body of the evaporator to evaporate more of the feed. The condensate is removed through the heat exchanger used to preheat the feed.

Variations of the simple vapor recompression still are the rotary and wiped-film stills. In these the advantage lies in high heat transfer coefficients. In the rotary still (Figure 9), for example, high heat transfer coefficients are obtained by spinning the

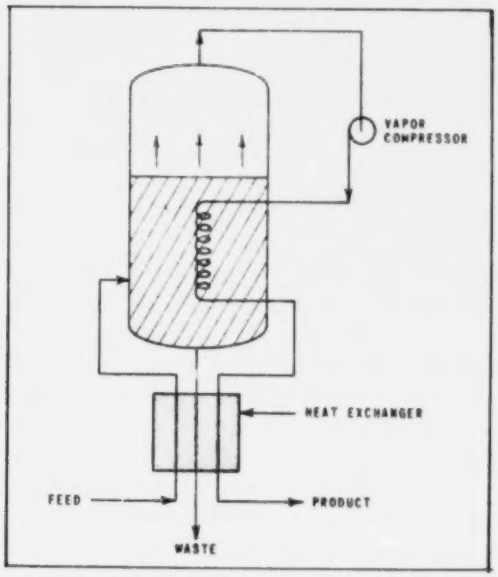


**Figure 8. Evaporation - vapor compression**

heat transfer surfaces, causing the evaporating liquid fed from nozzles onto the inside of a rotor to travel outward on the rotor as a thin film. The concentrated waste liquor is thrown to the outer periphery where it is scooped off by a collector and discharged through a heat exchanger. The steam produced passes through a recompressor in which its temperature is increased incrementally and is then fed back into the chamber containing the rotor. Condensation occurs on the outside surface of the rotor from which the condensate is thrown by centrifugal force to be collected as product. Preliminary tests in which primary sewage effluents have been processed through such a still have yielded encouraging results.[24] Chemical oxygen demand has been reduced by over 90 percent, synthetic detergents by over 95 percent, and chlorides by more than 99 percent. The investigator concluded, "The verdict of this experiment is that the recovery of water from sewage effluent is simple and the product acceptable." Further, "... the physical properties, flavor and odor of the distillate were excellent; with mild chlorination or equivalent, the distillate would be potable and acceptable for municipal reuse."

A process that has caught man's imagination for centuries is solar distillation - the use of the sun's free energy to distill water.

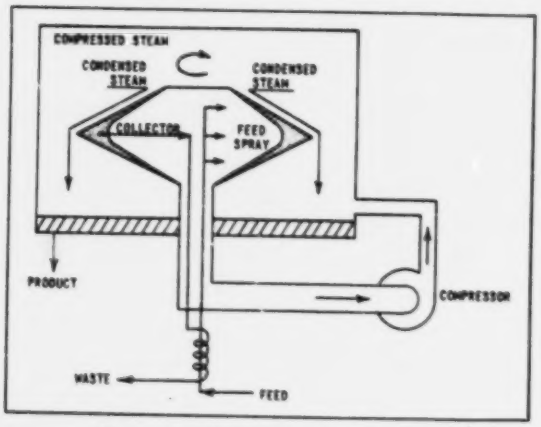


Figure 9. Evaporation - rotary still

One might believe that such a system could not be seriously considered in a nationwide program. After all, the sun's rays would only be hot enough in Florida or in the Southwest! But some investigators in this field are not so sure. Data on average solar intensity in July, for example, show almost the same values for Washington, D. C., and Bangor, Maine, as for Miami, Florida.[25] If so and if, as is claimed by people who have studied solar distillation, ambient temperatures are not too important because these systems can be insulated, perhaps solar distillation is even feasible in New York or Maine. In solar distillation (Figure 10) sunlight passes through a transparent film and is absorbed in a body of water. The heat generated serves to evaporate water that is then condensed on the inner surface of the transparent film. The heat of condensation is carried away by atmospheric air, and the condensate or product runs down the film and is collected in a trough. This is conventional solar distillation. But what if forced convection techniques rather than natural convection are used to convey water vapor to the condensing surface? This could make possible the use of an external condenser and, of more significance, would allow reuse of solar energy. In other words, the principles of multiple-effect evaporation could be applied.[26] As of now, it is not known whether or not solar distillation could be used as a primary separation technique - if not, perhaps it is a method for further concentration of wastes, following an initial stage.

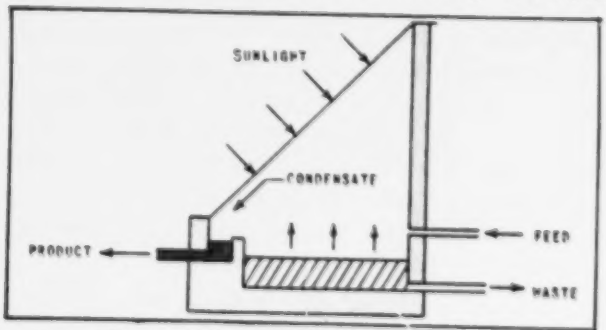


Figure 10. Evaporation - solar distillation

Finally, in regard to evaporation, it is important to recognize that although a number of problems remain to be solved in developing practicable evaporation processes for waste water renovation certain of the major difficulties encountered in evaporation of more highly concentrated solutions, e. g., sea water, may be minimized when municipal wastes constitute the feed stream to the evaporator. Because of the relatively low concentration of impurities in the feed, it is possible to perform most of the evaporation from rather dilute solution. In other words, the bulk of the water product may be obtained in equipment free of appreciable boiling point rise, free of corrosion problems, and, of great significance, free of scaling difficulties.

## Extraction

Solvent extraction (Figure 11) is yet another possibility. It should theoretically be possible, in this instance, to remove either the contaminants from the water or water from the contaminants. It seems obvious that the better scheme is to remove the contaminants from the water because there is much less material to remove. But because of very low actual efficiencies in all processes being considered to date, it is not at all certain that one way is really better than the other in practice. In Figure 11, a solvent, introduced into the bottom of the extraction column, rises up through the column and comes in direct, intimate contact with the feed stream passing downward countercurrently. With the proper solvent, contaminants would be removed from the feed to dissolve preferentially in the solvent. The solvent-contaminant solution or "extract" is then led into a separator in which the solvent and the contaminants are parted, perhaps by a slight change in temperature. The concentrated waste stream is then thrown away or subjected to further concentration while the solvent is

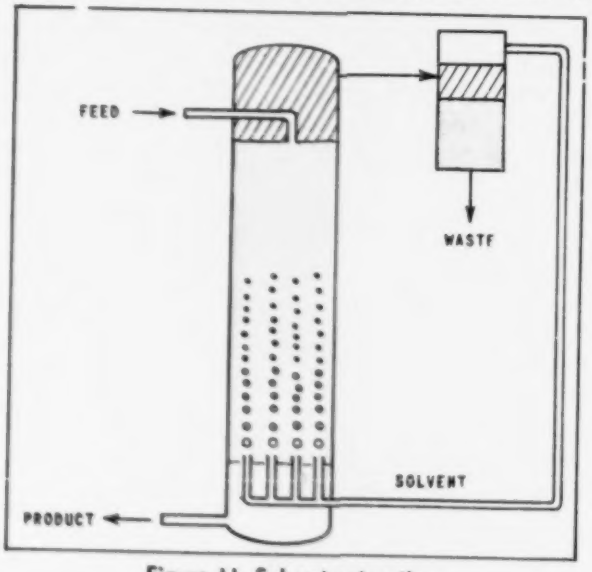


Figure 11. Solvent extraction

recycled to the extraction column. The one thing needed here is, of course, a solvent in which all contaminants will be more soluble than they are in water, the "universal solvent." This solvent, obviously, has not been found to date.

Even if all contaminants were not removed, however, solvent extraction might be of value for selective removal of certain classes of material. It is not unlikely, for example, that certain organic contaminants could be removed by extraction into organic solvents. The major concerns here, however, are that the feed would be contaminated by the solvent, i. e., a secondary pollution problem would be created, and that the contaminants would be more difficult to remove from the solvent than they were from the water in the first place.

The second approach is to extract the water from the contaminants. This possibility is now being studied for desalination purposes. It can be accomplished by use of secondary or tertiary amines, for example, as the solvent,[27] but little is known regarding its feasibility in the treatment of wastes.

## Emulsion Separation

Another category of separation by liquid-liquid contact involves the phenomenon of emulsion formation (Figure 12). It is known that certain solutes tend to concentrate in the monomolecular layer exactly at the interface between immiscible liquids. In organic solvent-water systems, molecules having hydrophilic and organophilic ends would exhibit this tendency. Therefore, in such an "extraction" the extractive capacity and the rate of extraction depend not on the volume of solvent used but on the interfacial area between liquid phases. Such a separation can be carried out with a relatively small volume of solvent if a fine emulsion is generated. The emulsion phase can subsequently be removed and "broken" to recover the solvent for recycle to the system. Preliminary experiments on the applicability of this technique for advanced waste treatment purposes are now in progress.

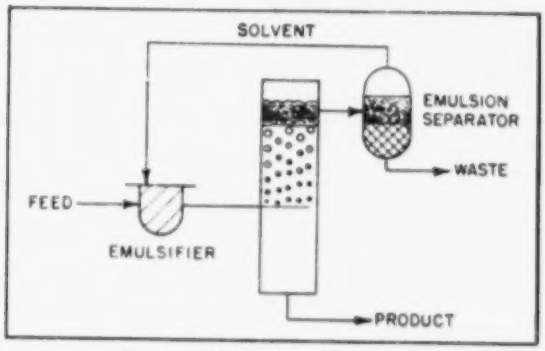


Figure 12. Emulsion separation

## Foaming

The foaming process (Figure 13), another possible separation

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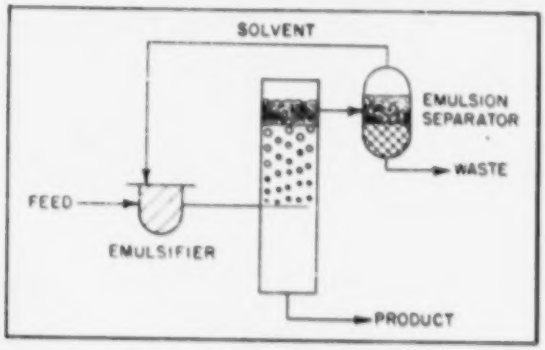


Figure 12. Emulsion separation

## Foaming

The foaming process (Figure 13), another possible separation

technique, is similar in many ways to emulsion separation, except that a gas forms the second phase of the system rather than another liquid. "Foaming" should be distinguished from "froth flotation." Froth flotation, a principle that has been used in metallurgy and even in waste treatment for a number of years, operates on suspended particulate matter - not dissolved materials; it operates by causing air bubbles, introduced into the bottom of a tank, to associate with the particulate matter, to adhere to it, and to decrease its density artificially. This causes the particles to be carried upward and out of the bulk stream because of their greater buoyancy. In addition to removing this suspended matter, however, a second fundamental separation mechanism occurs causing dissolved materials to be simultaneously removed from the bulk liquid. This takes place because many materials, in fact, all water-soluble organic compounds, are surface-active to some extent; that

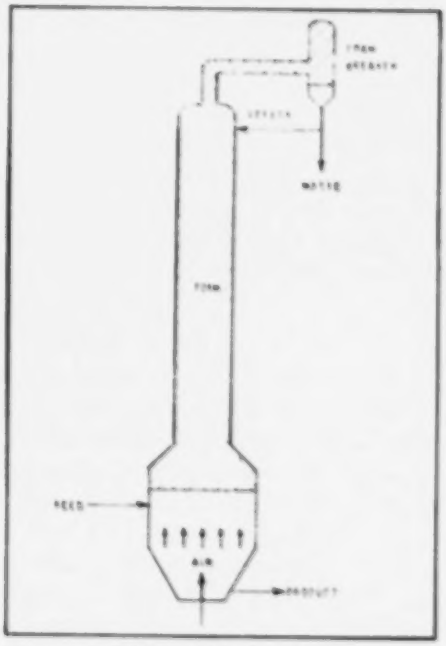

Figure 13. Foaming

is, they tend to concentrate at a gas-liquid interface, as predicted by the Gibbs equation. If the liquid near the air-water interface is removed, skimmed off, for example, some of the soluble compounds present are removed. If there is only a pool of water, there is only one relatively small air-water interface, but if bubbles are blown up through this pool, the foam produced has a very large air-water interfacial area. When this foam is removed and collapsed, it contains a higher concentration of surface-active materials than was present in the original feed solution. This is simple, single-stage foaming. Experiments conducted to date[28, 29] have demonstrated that the synthetic detergent concentration of secondary sewage effluents can be reduced by 80-90 percent by

this single-stage foaming. To increase the degree of separation, foam fractionation can be employed. There is an almost direct analogy between foam fractionation and fractional distillation. It is possible, for example, to recycle some of the collapsed foam back to a foam column as reflux. This washes out the bulk liquid held up in the column and enhances the separation possible, just as reflux does in a distillation column. There are certain possible innovations foreseen in foaming technology. Trace quantities of certain non-surface-active ions have been removed from solution through foaming by "complexing" them with surfactant materials.[30] Could this same principle be applied to remove non-surface-active or only slightly surface-active contaminants from waste streams? Or, why not "seed" the waste stream with some cheap, highly surface-active material, for example, lignosulfonic acid, a waste product of the sulphite pulp industry? It might be possible to make use of the increased foamability of the feed to achieve removal of even only weak surfactants in a crude, single-stage foaming operation. Then, in an auxiliary foam fractionation column, the seed material could be recovered for recycling and the contaminants further concentrated. Beyond this, it has been suggested that foaming and adsorption would result in a highly effective "team" for the economic removal of organic impurities from water[31] - foaming to remove the high molecular weight surfactants which tend to resist removal from the adsorbent during regeneration, and adsorption to remove the remaining low-molecular-weight compounds.

## Freezing

Freezing is a comparatively new large-scale separation process that has received appreciable attention for conversion of saline waters. It may also apply to renovation of waste waters. Figure 14 illustrates the direct freezing process. Feed water is sprayed into a vacuum chamber operating at about 3 millimeters Hg absolute pressure. Part of the feed is flash evaporated, which produces a cooling effect and causes formation of fine ice crystals in the mother liquor. These ice particles are normally very, very fine - on the order of 1 to perhaps 1000 microns in diameter - and are essentially pure $H_2O$. Obviously the larger the crystals are, the better - the easier they are to handle, to wash, etc. The ice slurry formed is pumped over into a wash column in which it rises countercurrently to a small volume flow of wash water. The washed ice is then melted by condensation of the very same vapors that were removed from the vacuum chamber. This is accomplished by using the vapor compression principle described earlier to create the necessary temperature-driving force. One variation in this process involves the use of an absorbing liquid to condense the overhead vapors. Subsequent recovery of the latent heat of condensation is accomplished through heat exchangers.

A disadvantage of the direct freezing process is the tremendous vapor volume that must be conveyed and compressed. This, of

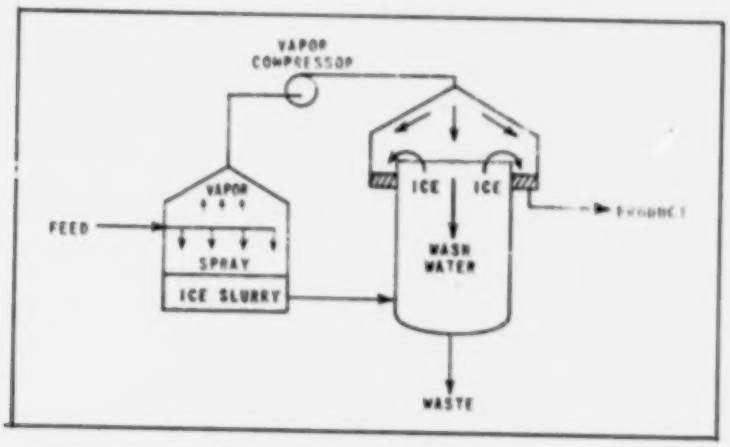


Figure 14. Freezing - direct

course, is a consequence of the very low absolute pressure at which the system must operate. Use of a secondary refrigerant in direct freezing can minimize this problem (Figure 15). Here, the feed stream is also injected into a chamber, but rather than operating under high vacuum so that the feed water evaporates, the system operates under only a slight vacuum or even under pressure, and a secondary refrigerant, butane, for example, is expanded into this chamber so that it evaporates instead of the water. This serves to cool the feed so that, once again, small ice crystals form. The ice slurry is handled in much the same way as that from the direct freezing process already described. The refrigerant vapor, much smaller in volume than the water vapor at high vacuum, is compressed and used to melt the ice in the washer. As the ice is melted, the refrigerant is condensed to a liquid and mixes with the melted ice. The water and liquid refrigerant flow to a decanting chamber where they are separated, the refrigerant recycling to the freezer and the water going to further processing or to product storage. One problem in this system is contamination of the product by the secondary refrigerant. The product water becomes saturated with this material during melting. It is believed by many workers in this field that it will be very simple to remove and recover traces of refrigerant from the product water. Unfortunately, however, it has not been established how much residual refrigerant is permissible. Toxicologically, there is probably no problem with butane or other hydrocarbons. But what about the explosion hazard, and what about the possibility of even very small concentrations of these hydrocarbon materials acting as nutrients for bacteria, algae, etc., in a distribution system? Also, in spite of the work done on the freezing process over the past decade, little if anything is known of the fate of bacteria, virus, or even common organic contaminants within the freezing process. There are certainly a number of unanswered questions about this process, but it cannot be overlooked as a serious possiblity for advanced waste treatment purposes.

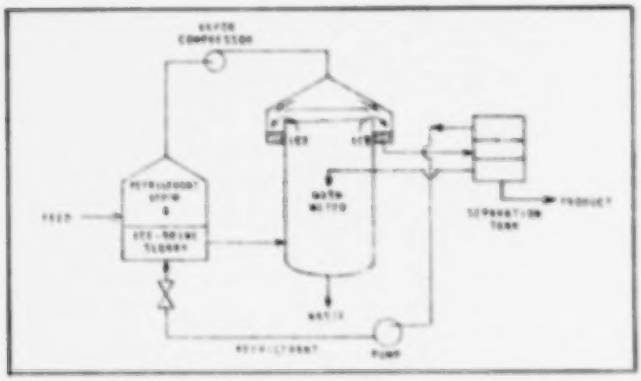

Figure 15. Freezing - secondary refrigerant

A very interesting extension of "conventional" freezing has been proposed in a special report prepared for the Advanced Waste Treatment Research Program.[32] This process, termed "eutectic freezing," would be used to achieve very high concentration ratios by operating at the eutectic point of the feed, thereby rejecting from solution pure ice and precipitated contaminants simultaneously. It is theorized that this operation could be carried out at about -10°F, and that it would result in the continuous discharge of two slurry streams: one, ice to be melted as product, and the other, a highly concentrated waste containing all impurities present in the feed, both organic and inorganic. The economics of such a process are not unfavorable in spite of the low process temperature, because the eutectic freezer need be used on only a small fraction of the total plant throughout, i. e., on the already-concentrated brine discharged from some primary concentration stage. A flow sheet for this process is shown in Figure 16.

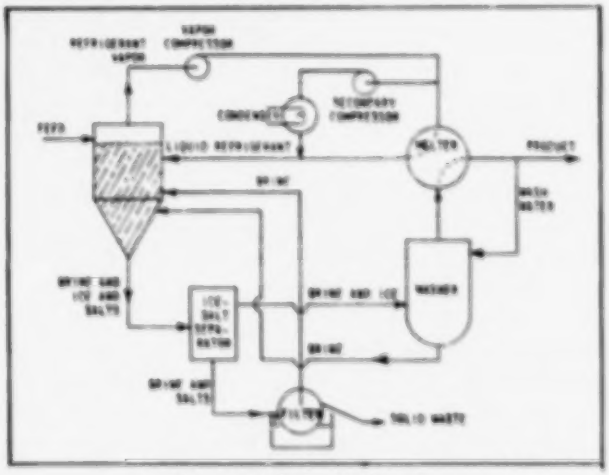

Figure 16. Eutectic freezing

## Hydration

The hydration process, Figure 17, is very similar to freezing; in fact, it is essentially the same phenomenon. A hydrate-forming

gas, possibly propane, is bubbled into a "reacto " (rather than into a freezer) in which fine crystals of a solid hydrate are formed. The contaminants are excluded from the crystalline structure. Propane, for example, will, at 50-60 lb/in.$^2$ and 35°F, form a solid hydrate with 17 or 18 molecules of water per molecule of propane, again as very fine ice-like crystals. The slurry is then pumped over into a wash column in which it is washed with a small portion of the product water. The hydrate crystals are transferred to a decomposition chamber where the hydrate is caused to decompose by a change in temperature and/or pressure. Product water is pulled off by simple decantation and the hydrate-forming material is sent back to the original reactor.

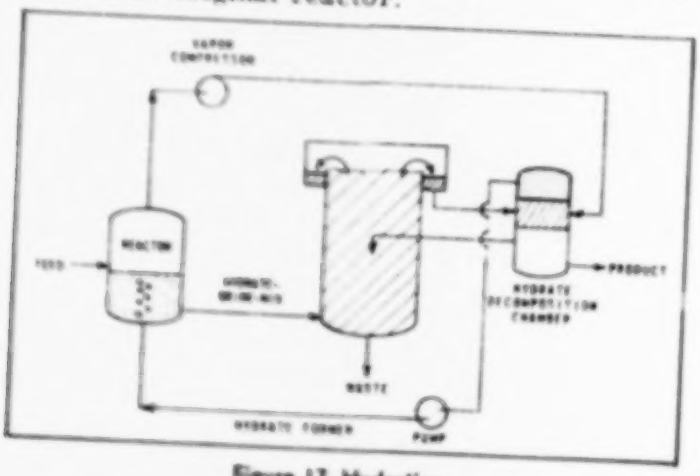


Figure 17. Hydration

Gas hydration has certain thermodynamic as well as practical advantages over freezing. These advantages may be increased by use of hydrating agents that form hydrates at temperatures closer to ambient conditions. Hydration may, in fact, be thought of as a high-temperature freezing process. In addition to propane, a number of water insoluble compounds, e.g., methyl bromide, ethyl fluoride, many other halogenated methanes and ethanes, and even inorganics such as chlorine will form solid crystalline hydrates under appropriate conditions of temperature and pressure.

## Oxidation

Although not strictly a "separation" process, oxidation is being considered because of its potential ability to destroy organic pollutants directly in dilute aqueous solution (Figure 18). The questions are: Can economical oxidation of organic substances be performed in highly dilute solution and can ozone, hydrogen peroxide, chlorine, chlorine dioxide, or other powerful more exotic oxidants be used for this purpose? Chemical oxidation is but one of several possibilities. Electrolytic oxidation could hold promise. Catalytic agents might be employed, even, perhaps, so that atmospheric oxygen could serve as the oxidant.

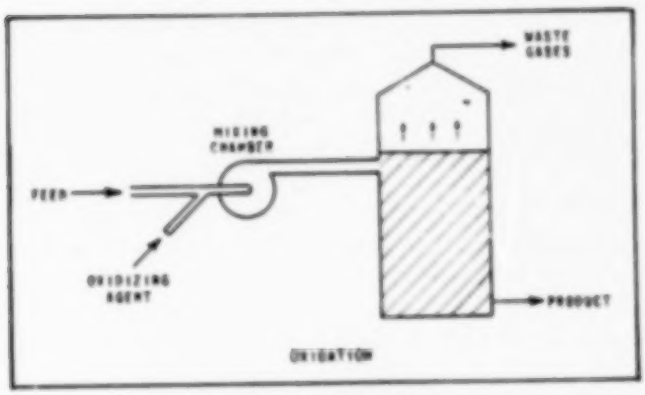


Figure 18. Oxidation

## Ion Exchange

Ion exchange is another possibility for renovating waste waters. Small inorganic ions may be removed by conventional ion exchange in packed-bed, mixed-ion exchange columns (Figure 19). When the ion exchange capacity of the bed has been depleted, the feed is stopped and a regenerating solution passed through the bed. In this sort of system provision must be made for disposing of the regenerating solution itself. An interesting innovation is illustrated in Figure 20. As a cation enters the mixed-bed ion exchange column, it is removed by exhange on a cation bead. This collected ion is then subjected to a driving force imposed by an electrical field impressed across the whole bed. The cation then moves through the resin just as it would migrate through any electrolyte

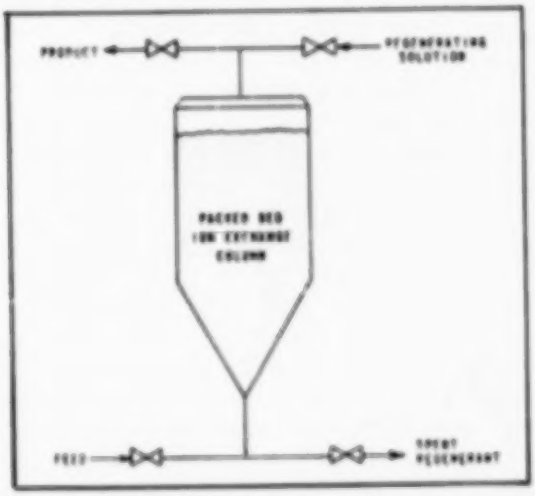


Figure 19. Ion Exchange - counter exchange regeneration

solution. It moves through the solid electrolyte in the direction of the cathode and jumps from one bead to another along a continuous solid path to a cation-permeable membrane at the boundary of the bed. As the cation passes through this membrane, it enters

a waste carrier stream and is flushed out of the system. Similarly, anions travel in the opposite direction and are flushed out. Once again the same sort of precipitation idea discussed under electrodialysis could be utilized to allow the waste carrier stream to become supersaturated within the unit and to deposit essentially damp salt, by precipitation, in a unit outside. This scheme of electrical regeneration of ion exchange resins is of current interest, as is the possibility of synthesizing exchange resins satisfactory for organic as well as inorganic ions.

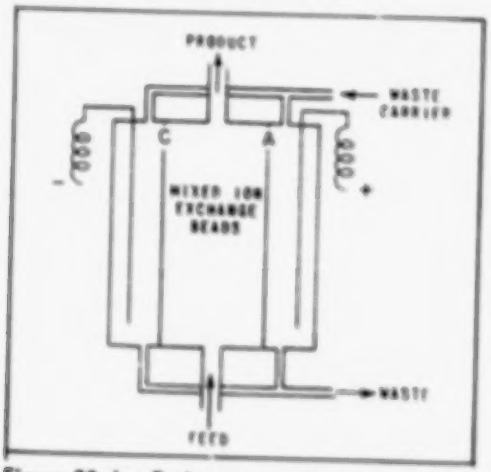


Figure 20. Ion Exchange - continuous operation

## Electrochemical Degradation

Appreciable evidence exists in the literature that many organic compounds are capable of participating in electrode reactions. The electrolysis of certain organic acids in aqueous solution can lead to complete decomposition; a report exists[33] of the complete electrolytic degradation of phenol disulfonic acid to $CO_2$, $H_2O$, and sulfuric acid - the implication regarding alkyl benzene sulfonates is obvious. In addition to acids, many organic compounds including alcohols, aldehydes, carbohydrates, esters, and even hydrocarbons exhibit measurable conductivity in water. It is evident, therefore, that electrochemical treatment could offer some promise in advanced waste treatment. The goal would be electrolytic decomposition of contaminants into simple innocuous molecules or merely conversion of relatively complex, refractory organics into biologically "soft" or generally non-refractory form (Figure 21).

A major fraction of the cost of any electrochemical installation involves the supplying of direct current. Some promise has been indicated for alternating-current electrolysis of aqueous organic solutions.[34] Only irreversible electrode reactions are possible, but, fortuitously, many organic electrode reactions should fall in this class. Further advantage might be gained through use of ultrasonic agitation to catalyse electrode reactions, thereby reducing power requirements. It is known that this technique can

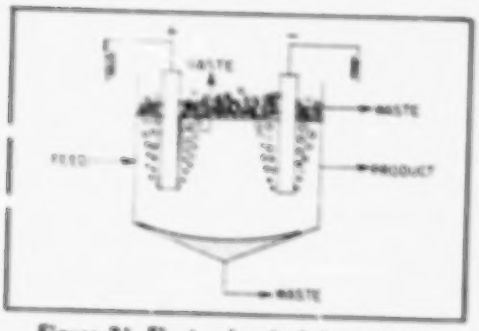


Figure 21. Electrochemical degradation

appreciably lower the voltage required for the electrolysis of water.

## PERMANENT DISPOSAL PROCESSES

There appear to be four general possibilities for ultimate disposal of concentrated wastes. The first, recovery of usable products from the waste, is undoubtedly the most desirable, and yet very possibly the most unlikely. Such a solution - the conversion of a waste to a valuable product - could eliminate the "disposal" problem altogether and could conceivably produce revenue that would help defray the cost of advanced waste treatment. A number of products suggest themselves: structural material such as brick or building blocks, road paving, aggregate for concrete, fillers for various materials, soil conditioners, and insulation, for example. Many cities could make use of recovered salts for street deicing during winter months. The recovery of chemicals and even extraction of pharmaceutical products is not impossible. Of course, fertilizer values present in municipal wastes are even now utilized in some cases. Sludge particles may have adsorptive properties, or these characteristics might be developed through proper activation. Concentration of surfactants from the condensed foam of a foam fractionation process could be an important source of industrial detergents in the future. These and many other useful products may one day make the concept of multiple reuse apply not only to the water fraction of our municipal waste streams, but to the non-aqueous material as well.

The second method of ultimate disposal is simply "dumping." By this we mean disposal of highly concentrated wastes to some waste sink. Included in this method would be dewatering and drying of a sludge with subsequent disposal as land fill, discharge of brines to evaporation lagoons or to natural or artificial reservoirs set aside for this purpose, or transport to the world's "infinite waste sink," the ocean. Transportation of residues to the "dump" may involve shipment over very great or very small distances. For communities at the seacoast, for example, disposal can be made almost in the "backyard" of the renovation plant. For inland cities, discharge might be through pipe lines, through canals, or by barge. It might even be feasible to store wastes temporar-

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ily in reservoirs for controlled discharge to a river at time of flood. Since aqueducts are in use today transporting many millions of gallons of fresh water hundreds of miles, is it so unlikely that concentrated wastes composing perhaps only one-hundredth or one-thousandth of these volumes could be piped similar distances economically?

Subsurface disposal is the third general category. This could, of course, be included as a form of dumping, but it is classified separately because of the unique problems associated with this type of disposal. Subsurface disposal may be either shallow or deep. With shallow disposal it is contemplated that reintroduction of the water fraction into usable ground water supplies may occur. In other words, disposal by soil-spreading or shallow-well injection can be done only when provision is made for rendering potentially harmful contaminants innocuous before they find their way into usable supplies. This could conceivably be accomplished by soil bacteria, by adsorption or ion exchange onto soil or other natural formations, or even through the addition of special chemical agents that could "neutralize" or destroy harmful contaminants during their passage through the ground.

In deep-well injection on the other hand, it is assumed that no contamination of existing or future water supplies could occur. The wastes are placed in strata so deep or so sealed that the wastes are forever removed from contact with human activity. Injection could be made into porous strata or into natural or artificial cavities such as salt domes, natural caverns, or abandoned mines. The feasibility of underground injection as an important disposal method depends, obviously, on the availability of suitable sites. Our Nation's resource of such reservoirs has not yet been completely assessed. Even beyond this, the compatability of advanced waste treatment concentrates with various underground formations cannot yet be established since the character of these concentrated wastes will depend upon the concentrating process to be used and this has not, of course, been established.

The final possibility for ultimate disposal lies in converting the refractory contaminants to innocuous materials. In many cases this might be done prior to and in conjunction with recovery of products, dumping, or shallow underground disposal. Generally, however, it would be a chemical conversion process that would produce a stream of suitable quality for release back into the environment. Today's biochemical processes of anaerobic digestion or aerobic fermentation may play a role. Few, if any, organic materials are completely inert to biological degradation - given enough time, under the right conditions, and in the presence of suitably adapted bacteria, even highly resistant materials could be oxidized. Biochemical fuel cells, one of science's very newest developments, might be employed to recover energy for use in the process. Treatment by high-energy radiation has been suggested as a means for sterilizing wastes and even for catalyzing

their oxidation to harmless materials. Certainly, the age-old waste disposal process, incineration, cannot be overlooked as a serious possibility. Equipment is now available in which still-wet sludge may be sprayed directly into a combustion chamber. A new contender in the waste disposal field is wet oxidation - aqueous-phase oxidation of dissolved and suspended organic matter at high pressures and in the 500°-600° F range. Techniques such as this, which do not require dewatering of the waste sludge, may have appreciable economic advantage in tomorrow's waste disposal technology. As in the case of product recovery, combustion processes may "pay their own way" if the heat value of oxidized materials is recovered for use - in other words, if the waste sludge is used as a fuel. To improve the economics even further, perhaps the fuel value of all of the organic wastes of a community (garbage, waste paper, sawdust, etc.) should be utilized. In fact, the day may come when advanced waste treatment plants perform the functions now accomplished separately by refuse disposal, garbage disposal, and sewage disposal plants.

## CONCLUSION

The question may now be asked, "On what criteria will the choice of a separation process and of an ultimate disposal process be made?" The overriding one, of course, is the technological adequacy of the processes themselves. The methods chosen must be capable of accomplishing the two objectives of advanced waste treatment mentioned earlier: (1) the permanent disposal of the water-borne wastes of a community, and (2) the production of a water product suitable for repeated reuse. It is a known fact, however, that a great many processes are, today, capable of doing these things. From this standpoint, the Advanced Waste Treatment Research Program is "doomed to success." The challenge, the measure of success, therefore, is economics! The process, or more properly the technology, that will achieve the above objectives at the very lowest possible cost must be devised, since it is foreseen that, in the future, a fair fraction of our country's fresh water supply may be produced in this way.

It is not expected that any one process will be universally applicable. The inherently varied nature of the problem, i.e., the character of the wastes to be treated, geographical and logistical factors, the intensity of reuse required, etc., is sufficient to make this probability extremely small. For every plant designed, a unique economic situation will exist that will determine the optimum separation process, the optimum disposal technique, and the optimum fraction of the total treatment job each will be required to do. The problem is complex, the task is formidable, but a solution can, at one step, solve our problems of water pollution and of water supply, and in addition could be a tremendously valuable weapon in the cold war for the many water-short areas of the world.

# ORGANIZATION OF THE ADVANCED WASTE TREATMENT RESEARCH PROGRAM

The Advanced Waste Treatment Research Program differs a great deal from the standard research program at the Robert A. Taft Sanitary Engineering Center, inasmuch as approximately 80 percent of the work is being done through outside negotiated contracts. The reason for this is that many of the techniques to be investigated require equipment and competence not readily available. To assist in the program the Public Health Service has enlisted the help of universities, private research institutes, and industrial concerns. A great deal of interest has been evidenced by the many organizations who have contributed to the program, and well over 100 contacts have been made with various groups who have interest in the program. Approximately 20 percent of the research is to be conducted in intramural laboratories.

## ADVISORS

The advisory group to the advanced Waste Treatment Research Program was appointed to assist in the conduct of the Program. The duties of this group include (1) suggesting novel approaches to the solution of the problem, (2) locating potential contractors, (3) reviewing technical scopes of work, and (4) evaluating research findings. The members of the advisory group are listed below.

Advisory Group

Mr. Paul A. Bonderson
Executive Officer
State Water Pollution
Control Board
Room 316, 1227 "O" Street
Sacramento 14, California

Dr. Clarence C. Cottam
Welder Wildlife Foundation
P. O. Box 1396
Sinton, Texas

Mr. James M. Gill
Ehtyl Corporation
P. O. Box 991
Pittsburg, California

Dr. Victor K. LaMer (Retired)
Department of Chemistry
Havemeyer Hall
Columbia University
New York 27, New York

Mr. Dwight Metzler
Director, Division of Sanitation
Kansas State Board of Health
State Office Building
Topeka Avenue at Tenth
Topeka, Kansas

Dr. Linvil G. Rich
Dean of Engineering School
Clemson College
Clemson, South Carolina

Dr. C. Fred Gurnham
Dept. of Civil Engineering
Illinois Institute of Technology
Technology Center
Chicago 16, Illinois

Dr. Louis Koenig
Louis Koenig-Research
6702 Blanco Road
San Antonio 12, Texas

Dr. Oram C. Woolpert
Executive Director
The Ohio State University
Research Foundation
1314 Kinnear Road
Columbus 12, Ohio

In addition to the advisory group, because of the large volume and wide variety of technical problems in a program of this scale, a number of technical consultants have been appointed to assist the administrative staff in reviewing and monitoring research work by outside contractors. The appointees to this consultant program are as follows.

## Technical Consultants

Dr. A. J. Barduhn
Professor, Department
Chemical and Metallurgical
Engineering
Syracuse University
Syracuse, New York

Dr. B. F. Dodge
Dean, School of Engineering
Yale University
New Haven, Connecticut

Dr. W. L. Faith
Consulting Chemical Engineer
2540 Huntington Drive
San Marino, California

Dr. J. A. Gerster
Professor, Department of
Chemical Engineering
University of Delaware
Newark, Delaware

Dr. C. Fred Gurnham
Dept. of Civil Engineering
Illinois Institute of
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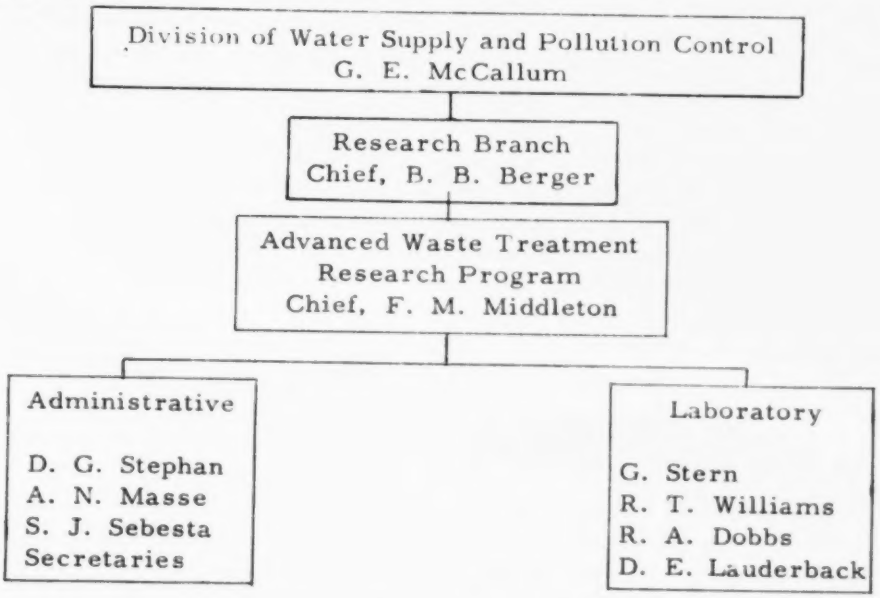
Dr. C. E. Lapple
Senior Scientist
Department of Chemistry
Stanford Research Institute
Menlo Park, California

Dr. W. Licht
Head, Department of Chemical
and Metallurgical Engineering
University of Cincinnati
Cincinnati, Ohio

Dr. A. J. Teller
Technical Director
Mass Transfer, Inc.
2000 Lee Road
Cleveland Heights, Ohio

The organization of the program is shown in the accompanying diagram.




# PRESENT STATUS OF RESEARCH

## INTRAMURAL RESEARCH

Projects within the intramural laboratory - the Exploratory Studies Laboratory - will be in three different areas: (1) detailed evaluation of various possible processes for use in renovation of waste waters, (2) contract support studies, and (3) exploratory research. Under (1) will be included projects similar in every way to those being undertaken extra-murally be contract researchers. These projects may cover the same principles of separation being studied under contract or they may be in entirely different areas. The primary objectives in undertaking in-house projects of this sort are to bring to bear on the over-all problem the extensive background and special competence of Public Health Service researchers in the waste characterization and waste treatment fields and to allow Program administration and coordination to be carried out with a firsthand working knowledge and appreciation of the unusual research difficulties involved in this area.

Contract support studies will provide direct assistance to contractors and to contract Project Officers to expedite the conduct and evaluation of the extramural research program. This will encompass development of special analytical procedures or experimental techniques, conduct of ancillary experiments to assist in determining the optimum course of future effort, and the carrying out of confirmatory experiments to verify results and conclusions obtained by contract researchers.

Preliminary studies of the possible potential and the ultimate technical feasibility of a number of as-yet unexplored approaches to waste water renovation will be conducted under "exploratory research". The exploration of "ideas" generated by contractors, by consultants, or by the Program staff will be the subject of these studies.

Intramural research has only recently gotten underway. To date, however, research has been initiated on oxidation of organics in dilute adapted solution, analytical procedures for ABS and COD have been adopted for use by AWT researchers, COD stability experiments have been made, the contributions to COD of certain secondary refrigerants used in freezing processes have been studied, and development of a method for assessing "foamability" of raw and renovated waste waters is nearing completion.

## EXTRAMURAL PROGRAM

As previously mentioned, approximately 80 percent of this Program's research is being conducted through negotiated contracts with universities, private research institutes, and industrial concerns. Principal areas of investigation initiated to date include adsorption, foaming, electrodialysis, ion exchange, and

Bob Williams of the Advanced Waste Treatment Research laboratory of the Public Health Service is running the chemical oxygen demand (COD) test. The test is a measure of the "strength" of carbonaceous organic waste materials. Assaying waste waters by the COD test before and after treatment is of help in evaluating the usefulness of a given treatment.

D. E. Lauderback of the Advanced Waste Treatment laboratory of the Public Health Service is running the methylene blue test for alkyl benzene sulfonate (ABS). ABS is the principal surfactant material in modern anionic synthetic detergents and is found in all sewages. Because of its foaming characteristics and its ability to resist biological degradation, it is important to find ways of removing ABS from waste waters. In the test, the methylene blue dye forms a complex with the ABS and following extraction into a solvent the concentration of the surfactant is determined colorimetrically.

freezing. Contracts have been awarded for short-term "desk-top" studies of distillation, freezing and hydration, extraction, and ultimate disposal techniques. The purpose of these desk-top studies is to obtain expert opinion and analysis of the potential applicability of a process prior to committing larger sums for contract work. Summaries of the contracts and reports completed or in progress through December 1961 follow. All findings of contractors are preliminary in nature and, although they are considered reliable, conclusions are not necessarily endorsed by the Advanced Waste Treatment Research Program.

Contractor: Louis Koenig - Research ($2380)

Project Director: Dr. Louis Koenig

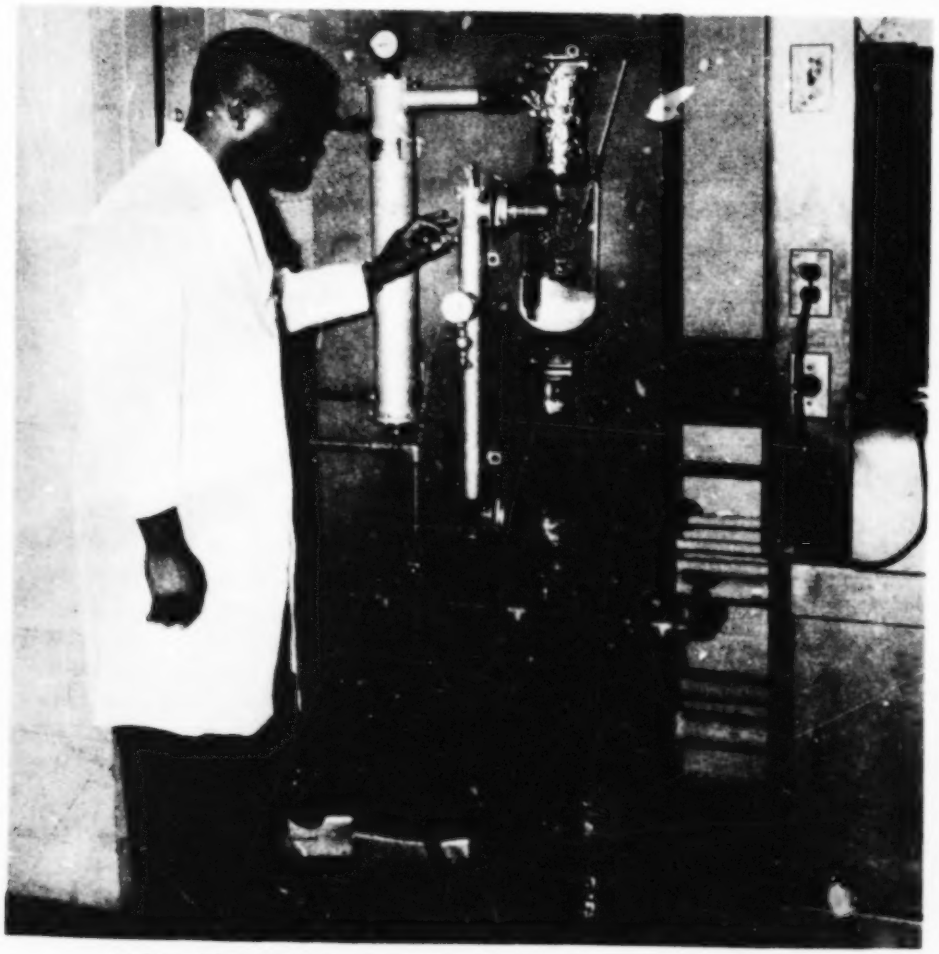
Period of Contract: August 1960 - January 1961

Purpose: Develop technical specifications for several advanced waste treatment processes

Summary

Very early in the Program it became apparent that a detailed study of the various physical and chemical processes being considered for the advanced treatment of wastes was necessary. Louis Koenig - Research, San Antonio, Texas, was given the assignment of preparing 14 technical specifications to serve as a basis for negotiating research contracts.

These specifications reported on a study of the various parameters affecting the freezing, extraction, hydration, foam fractionation, precipitation, oxidation, and adsorption processes. In the report the contractor presents information on the background of the processes, a bibliography of pertinent articles, and a suggested program of research for the purposes of renovating waste waters.



William Chaney of the Taft Center concentrates sewage effluent by vacuum evaporation. Concentration permits more direct study of the components in waters before and after use. The apparatus permits the concentration of several liters of liquid per hour and temperatures can be kept low to prevent destruction of sensitive compounds.

Contractor: Harvard University ($1500)

Project Director: Dr. J. Carrell Morris

Period of Contract: October 1960

Purpose: Appraise various methods of renovating waste waters

Summary

The report of this study provides a preliminary appraisal of currently proposed means and methods for economically securing more complete treatment of waste waters than is customarily attained. The appraisal is based upon ideas and proposals set forth in the recent literature in the water supply and waste treatment fields.

The need for such treatment is well defined. In the wake of a rapid population growth with increased pollutional loads on the water environment, there will be an increasing need for water reuse. In addition, the increased occurrence of substances that are not broken down biologically present new problems in waste treatment.

In Dr. Morris' opinion, the types of operations with the most promise are: (1) adsorption, (2) coagulation, and (3) chemical oxidation. Coagulation and adsorption processes are somewhat similar since the removal of impurities by coagulation is in part a result of adsorptive action. The distinction is that the adsorbent is formed in the medium rather than being added in a preformed condition.

Chemical oxidation appears likely to be an expensive process for achieving the desired degree of purification. Some of the oxidizing agents that have been tried in the waste water treatment field are oxygen, ozone, chlorine, and chlorine dioxide; however, any oxidizing agent that can be efficiently and economically obtained and employed may be used.

As a single step for salt removal in the treatment of waste waters, methods based on electrodialysis or ion exchange appear preferable. These methods are more economical for the treatment of a water that is relatively low in salt content, but become prohibitively expensive as the salinity increases.

Contractor: Dow Industrial Service ($25, 247)

Project Director: Mr. Thomas J. Powers

Period of Contract: December 1960 to February 1962

Purpose: Investigate the removal of residual organic

materials in municipal waste effluents by the use of activated carbon and study methods for reactivating the carbon by chemical means

Summary

A pilot-scale secondary treatment system was set up on the Midland, Michigan, primary effluent. The secondary effluent produced was put through a sand bed and became the feed to a series of activated carbon columns. Various carbons were evaluated and found to differ in adsorptive capacities for COD materials. One of the carbons was selected for study of regenerability by chemical means.

Regenerability tests consisted of exhausting the capacity of 50 grams of carbon (Cliffs-Dow) with secondary effluent and then attempting regeneration of the carbon by column exposure to oxidants such as potassium permanganate, chlorine, bromine, dichromate, hydrogen peroxide, potassium bisulfate, and sodium peroxide. When the concentration of the oxidant entering and leaving the column were equal, the carbon was considered regenerated. Various degrees of regeneration were achieved, the most effective regenerant found under the test conditions used was 3 percent hydrogen peroxide.

To date this study has helped to clarify the adsorptive capacity of activated carbon for organic contaminants and has indicated possible ways of using chemical regenerants.

Contractor: Dr. Allen J. Barduhn ($2000)

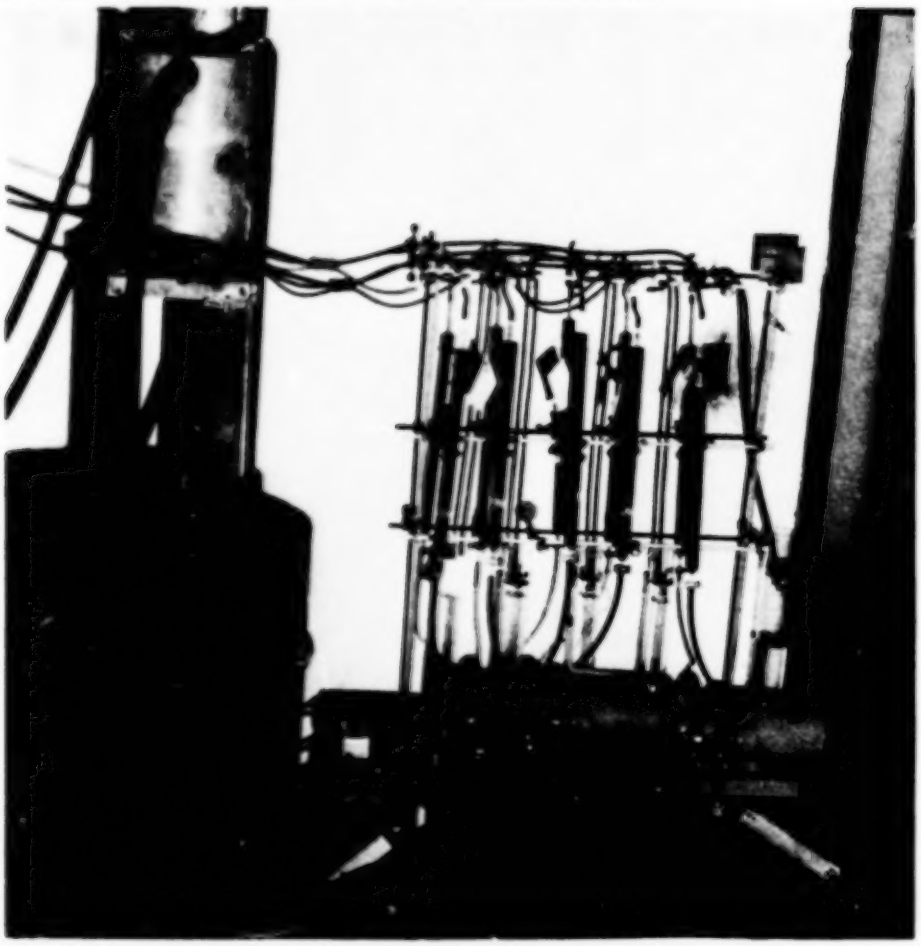
Project Director: Dr. Allen J. Barduhn

Period of Contract: February - June 1961

Purpose: Study feasibility of freezing or forming gas hydrates as a means of water renovation

Summary

In the report of this study the freezing and gas hydrate processes for demineralizing sea water were analyzed for application to the production of fresh water from waste water. It was concluded that either the freezing or hydrate process has potential for reclaiming most of the water in sewage by concentrating the dissolved solids to about a 1 percent brine and then disposing of this residue. Based on the estimating procedures developed by the Office of Saline Water, the approximate cost of producing fresh water by this process could conceivably be as low as about 39 cents



At the Dow Industrial Service laboratories, activated carbon columns are tested to determine their capacity to adsorb organic contaminants from secondary sewage effluent. The columns are then subjected to various chemical oxidants to determine whether the carbon can be reactivated by this means. Apparatus on the left of the picture is a model activated sludge unit needed to secure a secondary effluent.

per 1000 gallons, a figure considerably lower than that projected for sea water demineralization. This process is suitable only in areas where large volumes of concentrated waste may readily be disposed of.

Where the dissolved solids must be concentrated to a much greater extent, a second process devised for the purpose of removing the dissolved material in solid form can be used. This process is called eutectic freezing and involves removing both water and solids simultaneously at temperatures around -10° F. If most of the water is removed from sewage at higher temperatures and then the remaining concentrate is treated at -10°F, the cost of water produced could be about 50 cents per 1000 gallons. It is predicted with some confidence that the eutectic freezing process will remove not only the inorganic salts but also most of the ABS and other high-molecular-weight organic materials, since the

high concentration of salts will force the organic materials out of solution at the low temperatures used.

The volume of the final rejected wet solid residue will be one thousandth that of the feed; the problem of treating or disposing of this residue was not considered.

Contractor: W. L. Badger and Associates ($2500)

Project Director: Mr. Howard F. Bjork

Period of Contract: March - April 1961

Purpose: Survey advanced waste treatment problems and use of distillation as a separation method

Summary

The report of this study deals with the water contamination problem in the United States, the need for a new technology, and several specific processes for the removal of soluble materials from the effluent streams of both industrial and municipal sewage treatment plants.

The water contamination problem is, of course, changing very rapidly. Because of the changing nature of the problem and because of the increasing quantities of materials that must be removed, water treatment technology has not kept up with the needs. This calls for a new program that should depart radically from traditional sanitary engineering research. It should be guided by a technical and economic engineering evaluation, oriented only toward obtaining low-cost water by technically feasible processes.

Some of these processes might be evaporation, freezing, adsorption, hydration, solvent extraction, ion exchange, electrodialysis, or biochemical processes. The characteristic features, advantages, and disadvantages of these processes are discussed elsewhere in this report.

The basic problem is not only one of technical feasibility but of cost. For this reason costs of present-day processes for water purification and sewage treatment are presented for evaluation.

Contractor: Dr. Donald F. Othmer ($1000)

Project Director: Dr. Donald F. Othmer

Period of Contract: March - June 1961

Purpose: Analyze distillation and evaporation for use in renovating waste waters

Summary

Much of the work directed at producing purified water from contaminated wastes has been in the field of distillation and evaporation. In more-recent years, many sophisticated variations of the simple processes have appeared, largely as a result of the stimulation of the Office of Saline Water. The report of this study discusses some of these techniques that could be applied to waste waters.

These distillation and evaporation techniques with modifications have had for their principal object the separation of fresh or potable water from sea water or brackish water. Invariably, a tremendous sump of contaminated water and also a tremendous sump for disposal of concentrated brine have been assumed to be available.

In most evaporation and concentration processes for the desalination of sea water, it is not propitious to produce a waste with a salt concentration more than two or three times that of sea water. Greater concentration elevates the boiling point in the evaporators, causes formation of scale, increases carry-over of impurities, and is unnecessary because of the availability of a tremendous waste sink.

In advanced waste treatment, particularly if applied after secondary treatment, the dissolved solids content of the feed is usually low enough that elevation of boiling point would not be important in concentrating the feed up to perhaps five or six times. However, the solids must usually be concentrated and removed as such since in areas removed from the sea shore, there would not be an infinite sump for disposal of one-half to one-third of the original feed.

Some of the evaporation processes considered in the report of this study are: (1) multiple-effect evaporation, (2) vapor compression evaporation, (3) flash evaporation, and (4) vapor reheat evaporation. These systems may be modified or combined in many ways for specific uses. No one is optimum for all operations. Many local factors, including source and temperature level of heat available and the possibility of incorporation into a thermal power project, should be considered.

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| Contractor: | Dr. K. C. D. Hickman ($2500) |
| Project Director: | Dr. K. C. D. Hickman |
| Period of Contract: | March - May 1961 |
| Purpose: | Evaluate factors affecting recovery of waste waters by freezing and distillation |

Summary

The report of this study provides sketches and explanations of the freezing and distillation processes considered most likely for waste water purification. Dr. Hickman proposes that potable water recovered from waste water will be accepted as a necessity in future years and that it will have the advantages of being "on the site," delivered without freight cost or political obligation, and will not increase the load on local wells or rob a neighboring community.

With orderly improvements, it is predicted that the cost of processing waste waters for reuse will add a cost burden of $20-$30 per capita per year.

Dr. Hickman's recommendations are that representative samples of waste water be run through every type of existing freezing and distillation equipment. Attractive processes for early study are flash distillation and compelled-film distillation.

In an appendix, Dr. Hickman describes a test run on a rotary still he designed. In the test he used primary effluent from a municipal plant as feed material. Analyses showed that the COD was reduced by over 90 percent, the chloride by more than 99 percent, and the detergent by over 95 percent. The author states that "the physical properties, flavor, and odor of the distillate were excellent" and that "with mild chlorination or equivalent, the distillate would be potable and acceptable for municipal reuse."

Contractor: Dr. J. A. Gerster ($750)

Project Director: Dr. J. A. Gerster

Period of Contract: March - April 1961

Purpose: Determine the factors involved in distillation of waste waters for reuse

Summary

Cost estimates were developed for the removal by distillation of under 1000 mg/l of nonvolatile organic and inorganic contaminants from surface waters. Various sources of heat energy and various types of equipment were considered.

Two processes were recommended. These appear capable of producing potable water at a cost perhaps 8 cents less per 1000 gallons than when sea water is used as feed. These are multiple-effect evaporation and multi-stage flash evaporation.

Both processes use exhaust steam from power-generation turbines as their heat source. Both processes also employ reuse of steam, permitting 25 pounds of water to be evaporated per pound

of steam supplied. Despite this good economy, 37 percent of the total water cost is the cost of steam.

In addition, in his report Dr. Gerster presents a detailed discussion of the energy sources that could be used for distillation. One possibility is that in 10 years or so steam generation by nuclear reactors may have become more economical than exhaust steam from power-generation turbines.

Another important conclusion is that because of the small concentration of contaminants found in waste waters power requirements could be about 15 percent less for distilling potable water from waste water than from sea water. Also, any less-severe corrosion and fouling potential occuring in waste water distillation would produce further economies over sea water distillation.

Contractor: Louis Koenig - Research ($750)

Project Director: Dr. Louis Koenig

Period of Contract: March 1961

Purpose: Perform orientation study on subsurface disposal

Summary

This contract called for a review of current literature and reports that might relate to subsurface disposal of advanced treatment concentrates.

It was determined that a study specifically directed toward advanced waste treatment needs was necessary since presently available material does not provide cost estimates over the range of parameters likely in advanced treatment disposal. Also, existing theory does not allow computation of reservoir capacities and injection pressure - cumulated injection volume relationships for disposal formations of the types that actually will be encountered. Further, current information does not provide details on the national distribution of likely injection sites, and thus cannot answer the question of whether injection may be applicable only in restricted areas. Finally, existing reports provide no information on disposal by placement in natural or artificial cavities.

For these reasons, a plan for a study of subsurface disposal was submitted. In this plan the author proposes to set up three possible waste concentrations and three flow rates and then make computations on the nine possible combinations. For each of these combinations, studies of the following factors are recommended:

1. Costs for over-all operation - purification and disposal.
2. Preconditioning that may be necessary before disposal.

3. Acceptance mechanism by which the formations will accept injected water. (In this the author enumerates several acceptance possibilities, which, for the most part, are the reverse of the mechanisms that force petroleum to a producing well.)
4. Theoretical injection rate - injection pressure relationships.
5. Types of facilities needed.
6. Disposal reservoir capacity.
7. Existing geological and geophysical data on a few areas that might be of interest relatively early in the application of advanced waste treatment.

It was also recommended that disposal of concentrate by placement in natural or artificial cavities be evaluated.

Contractor: Radiation Applications Incorporated ($30, 940)

Project Director: Dr. Herbert M. Schoen

Period of Contract: April 1961 to April 1962

Purpose: Develop foaming as a technique for removal of refractory organic materials from waste waters

Summary

At Radiation Applications, Inc., the effectiveness of foaming as an advanced waste treatment process is being evaluated. It has been shown that single-stage batch foaming can consistently reduce the alkyl benzene sulfonate concentration of secondary effluents by 80-90 percent. In continuous bench-scale equipment the same result can be readily achieved. The general relationship between gas volume - feed volume ratio (G/F) and product concentration has been established and a "maximum practical operating limit" for G/F can now be estimated. In continuous equipment, detergent concentrations apparently can be reduced to at least 0.2-0.4 mg/l and product-waste ratios as high as 1000:1 obtained. Assessment of the value of additives to the feed stream has just been initiated. These tests are being conducted in a continuous column specially designed to enhance the effectiveness of additives utilized to improve the removal of weak surfactants.

GPO 819664-5

Contractor: Polytechnic Institute of Brooklyn ($25,510)

Project Director: Dr. Harry P. Gregor

Period of Contract: April 1961 through August 1962

Purpose: Develop synthetic adsorbents for removal of refractory organic materials from waste waters and conduct a feasibility study of electrodialysis as an advanced waste treatment

## Summary

A dual program contract has been awarded to the Polytechnic Institute of Brooklyn. One effort is being directed toward the synthesis of new oil-swelling ion exchange resins that would be capable of removing various organic contaminants from waste waters. A number of such resins have been synthesized. A preliminary characterization of these new materials is now underway, and results to date indicate unusually high exchange capacities for both organic anions and cations. It is predicted that these resins should be largely nonselective and, therefore, capable of removing large classes of materials from waste waters; it may also be possible to achieve concentration ratios on the order of 500:1

The second effort under this contract involves the design and evaluation of a new type electrodialysis cell. Such a cell would

Dr. Harry Greger (left) and Mr. Talaat Saber study electrodialysis cell performance at Brooklyn Polytechnic Institute. A variety of membranes are under test to determine their usefulness in treating waste waters. Special attention is being given to removal of organic molecules.

employ membranes capable of conducting both organic and inorganic ions and would feature certain innovations allowing it to function efficiently in the 500-mg/l dissolved-solids range, a range in which conventional cells encounter increasing power inefficiencies. Cells of this design have been constructed and are now being characterized with various synthetic solutions.

Contractor: Harvard University ($20,852)

Project Director: Dr. J. Carrell Morris

Period of Contract: May 1961 to May 1962

Purpose: Study a variety of adsorbents to determine their effectiveness in removing deleterious substances from waste waters

Summary

A variety of solid materials, including carbon, silicates, metallic oxides, and chemical precipitates, are to be studied to determine their effectiveness in removing organic contaminants from waste waters. Fundamental characteristics that will form a firm basis for engineering application are also to be studied.

ABS adsorption isotherms on carbon have been run, and the antagonistic or synergistic effects of mixtures on adsorption rates and capacities are being studied. Adsorption and desorption of ABS appear to take place reversibly.

Another phase of this contract covers investigation of better ways to analyze for organic contaminants in waste waters. Direct measurement of the carbon dioxide from combustion of these materials is being investigated.

Contractor: Dr. Karl Kammermeyer ($500)

Project Director: Dr. Karl Kammermeyer

Period of Contract: June - December 1961

Purpose: Survey and abstract articles of importance to advanced waste treatment that are appearing in German literature

Summary

Under the terms of this contract Dr. Kammermeyer surveys the German literature for papers or other items of interest to the AWTR Program. Monthly he submits abstracts all articles that

may be of interest to the Program along with personal comments on the information contained. The German literature often contains abstracts of articles from Russian and other journals and, therefore, is a good source of information on European work in the water field. Several important items have been brought to the attention of the Program through this contract.

Contractor: Louis Koenig - Research ($2490)

Project Director: Dr. Louis Koenig

Period of Contract: June - July 1961

Purpose: Evaluate ultimate disposal of advanced treatment wastes by wet oxidation

Summary

In this study the wet combustion process for oxidizing organic material under conditions of elevated temperature and pressure was evaluated as a method for disposing of the concentrated contaminants from an advanced waste treatment plant. In this process, atmospheric oxygen is used as the oxidizing agent to oxidize the complex organics in solution.

Nine hypothetical cases covered the flow ranges from 1000 gpd to 10 million gpd and the concentration ranges of organic contaminant from 100 to 100,000 mg/l. Reactor design data (for 80 percent removal of COD), process cost data, and other process parameters were developed from pilot plant data reported in the literature, from design data for plants not yet in operation, and from laboratory data, and from other information obtained from the developers of the wet oxidation process.

A theory of the reaction mechanism based on the available data was proposed to explain some of the peculiarities of the reaction. The postulates include: (1) that the over-all reaction consists of a sequence in which intermediate products of lower molecular weight are successively formed (2) that the reaction rate of each intermediate increases with increasing molecular chain length of the intermediate and (3) that the size of the molecular fragments produced in each step decreases as the temperature increases.

Plant costs per gallon per day of disposal capability vary from about $4 at 10 mgd to $80 at 1000 gpd; the effect of the feed concentration is minor. Disposal costs per thousand gallons of concentrate processed vary from about $1.40 at 10 mgd to $35 at 1000 gpd; again, the influence of the feed concentration is minor. Disposal cost in dollars per day is practically independent of the tons per day of organics in the feed at any given gpd feed rate. At the upper limiting concentration the cost per ton of organics oxidized varies from $141 at the lowest flow rate, 1000 gpd, to about $6 at

10 million gpd. In the report on this study charts are presented by which various interpolations of the above unit cost figures may be made. The fixed costs constitute a very large proportion of the total disposal costs.

Suggested areas for further investigation include the kinetics and mechanism of the reaction, the possibility of using oxidation catalysts, and methods of disposal of the organics still residual from wet oxidation.

Contractor: Applied Science Laboratories, Incorporated ($9750)

Project Director: Dr. Arthur Rose

Period of Contract: June 1961 to November 1961

Purpose: Determine the feasibility of freezing as a process for separating contaminants from waste waters

Summary

This contractor conducted a series of 14 test runs on municipal effluent, using a 40 gpd freezing plant. Evaporating isobutane in direct contact was used for heat removal. The feed was secondary effluent from the State College, Pennsylvania, municipal waste treatment plant. On all runs approximately 20 percent of the feed was converted to ice; three-fourths of the mother liquor was drained off, and the mush of ice and mother liquor was washed with a volume of tap water equal to the volume of mother liquor in the wash. The washed mush was then melted with condensing isobutane vapor.

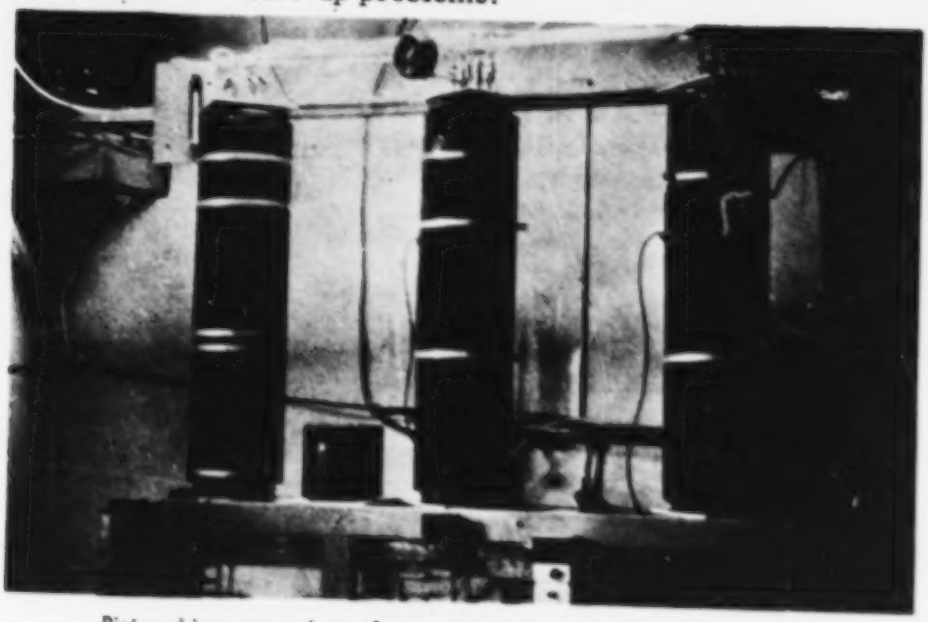
COD accountability was a problem throughout most of the runs in that much more (up to a factor of 3) COD was recovered in the products of the operation than was present in the original feed. This contamination was due in part to isobutane (which was found to exert an appreciable COD) and in part to oil leakage from the compressor and possible leaching of organics from gaskets, tubing, etc. In several of the runs, however, this was not a problem and it was determined that the impurities causing COD were reduced by a factor of from 3 to 8, chlorides by a factor of about 10, and conductivity by a factor of about 10. ABS was removed by a factor of 10 in some tests, but this was not consistent and the efficiency of the freezing operation for removing the detergent content of waste waters was not determined.

A very rough and preliminary cost estimate for waste water cleansing was made for a hypothetical plant having a freezing stage, a melting stage, and two washing stages, and with the feed

entering one of the washing stages. Under the assumption that the best runs made in the series of tests could be duplicated, it was estimated that a 95 percent yield of water with 90 percent of the contaminants removed could be achieved at a somewhat lower cost than the 30 to 70 cents per 1000 gallons estimated for desalting sea water by a similar process. Although this estimate is not rigourously defensible, it is believed to indicate the general neighborhood of the costs.

Based on his experience in designing and costing a one-million gallon per day desalination plant (with estimated production costs of 45 cents per 1000 gallons), the contractor states that the main savings in a waste water renovation plant would result from the lower contaminant concentration, which produces a smaller freezing point depression and, therefore, less power consumption. The reduction in energy requirements (about 20 percent) and the savings in compression equipment and heat exchangers (about 10 percent) could reduce the product cost by about 5 cents per 1000 gallons.

The contractor recommends a further series of 10 to 20 partial freezing and washing tests with isobutane refrigerant to obtain data for a more reliable cost estimate. In addition, he recommends some tests on a 1000-gallon-per-day scale to better understand the scale-up problems.



Pictured here are columns for conducting freezing tests on waste waters at Applied Science Labratories. Secondary sewage effluent was frozen by direct contact with isobutane and the frozen crystals were then washed and recovered. The experiment was a preliminary test to determine the characteristics of waste waters under these conditions and to find out whether freezing is a feasible method for removing contaminants from waste waters with recovery of clean waters as a benefit of the process.

Contractor: Ionics Inc. ($40, 608)

Project Director: Dr. Carl Berger

Period of Contract: July 1961 to June 1962

Purpose: Develop novel ion exchange resins and conduct a study of the use of ion exchange membranes in electrodialysis cells as an advanced waste treatment for waste waters

Summary

Ion exchange resins in bead and membrane form are well known for their properties in the removal of ionic materials. Less well known and much less studied is the possible usefulness of these materials in the removal of organic molecules. Studies are being conducted to determine whether novel exchange materials that would be highly effective in the removal of contaminants in waste waters can be developed. Ease of regeneration of such materials is an important factor.

Initial work with synthetic detergent materials (ABS) as a contaminant of interest showed that ABS is removed by anion exchange membranes - apparently by sorption effects. Membranes have been tailored to be more effective than standard membranes. Although the ABS can be eluted from the membranes by solvents, the material is not removed by reversing the current.

A large number of special resins will be tested against synthetic mixtures and sewage effluents to determine the effectiveness of separation of contaminants. A variety of electrical and physical desorption methods will be tested.

Contractor: Dr. Donald F. Othmer ($2250)

Project Director: Dr. Donald F. Othmer

Period of Contract: August - October 1961

Purpose: Determine feasibility of separation of biologically hard contaminants from secondary effluent by extraction

Summary

In the report of this study a process for removing biologically hard contaminants such as alkyl benezene sulfonate (ABS) from sewage water was proposed by the writers. It depends on taking advantage of the liquid-liquid interfacial activity of molecules of ABS between water and a water-immiscible solvent. The inter-

facial layer is skimmed off and treated with lime or milk of lime to precipitate the ABS as calcium alkyl benzene sulfonate. Since the calcium alkyl benzene sulfonate is water insoluble, it may then be removed.

The process would probably be operated in conjunction with other standard operations such as prior solids removal, biological treatment, or foam fractionation. Usually it would be operated on the concentrated overhead material resulting from a foam fractionation unit that would discharge 99 percent of the water with an acceptably low concentration of ABS. The other 1 percent, comparatively concentrated in ABS, could be discarded if there were a place or means for such disposal, but in those many places where no such place or means exist, the process suggested would probably be applicable. Many other exotic chemicals such as DDT or 2-4D would also be extracted in the solvent used in this proposed process.

A very rough guess was made as to the possible cost of its operation. These costs were estimated according to the practice of the Office of Saline Water of the U. S. Department of Interior, with the assumption that only about 1 percent of the volume of contaminants would actually be processed since about 99 percent would be purified by a foam fractionation unit.

The cost was estimated to be about 10 cents per 1000 gallons of sewage treated in a 1 mgd unit. This figure dropped to a roughly estimated value of 0.5 cents per 1000 gallons of sewage treated in a 10 mgd plant.

Contractor: Pittsburgh Chemical Company ($28,393)

Project Director: Dr. J. S. Mckay

Period of Contract: September 1961 to September 1962

Purpose: Conduct study of the economic feasibility of removing organic material from sewage effluent with granular, regenerable activated carbon

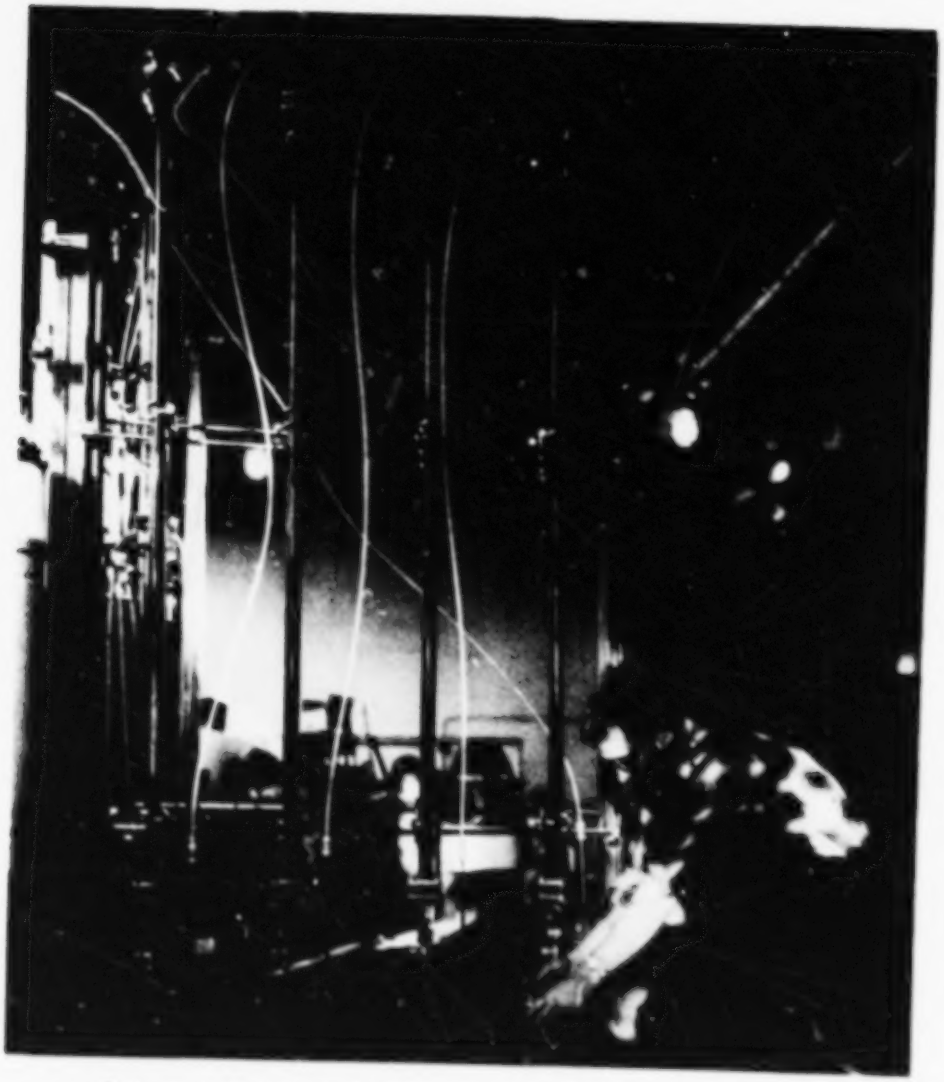
Summary

The capacity of commercial granular-liquid-phase carbons to adsorb synthetic detergents (ABS) and the mixed organic components in sewage effluents is being tested. A variety of flow rates, bed depths, and granular sizes are being evaluated. Carbon has been shown to adsorb 9 to 14 percent of its weight in ABS.

An important measure of the possible usefulness of activated carbon in removing contaminants is its regenerability. Prelimi-

nary tests indicate thermal reactivation is feasible, and this method as well as steam reactivation will be valuated.

At an early stage in the investigation it is planned to move these studies out of the laboratory to larger-scale tests on sewage effluents. A preliminary economic analysis will be made at the end of the first year of effort.



Engineer V. A. Sukenik of the Pittsburgh Chemical Company is collecting a sample of secondary sewage effluent that has been passed through granular activated carbon columns. The purpose of this study is to determine the capacity of the carbon for adsorbing organic contaminants and to study reactivation of the carbon by thermal and other means.

Contractor: Esso Research & Engineering Company ($49,820)

Project Director: Dr. I. A. Eldib

Period of Contract: October 1961 through August 1962

Purposes: Conduct exploratory investigation of foaming, alone and in combination with adsorption, and of emulsion separation for removal of soluble organic contaminants from waste waters

Summary

This recently initiated project at Esso Research & Engineering is devoted to studies of foaming and of emulsion separation. Foam-liquid-equilibrium data are being obtained along with surface tension - concentration relationships for waste water samples taken from various stages through a conventional sewage treatment plant. Measurements made to date have confirmed the often-reported visual observation that secondary effluent actually has a greater tendency to foam than primary effluent. The reason for this anomaly may lie in conversion of weak surfactant to stronger surfactants by biological action in a secondary process, destruction of foam inhibitors in the secondary unit, or simply a reduction of surfactant concentration to an optimum range for foaming.

Only a very few emulsion separation experiments have been undertaken so far. First indications are that emulsion stabilities will not be as great as foam stabilities - this has yet to be confirmed over a range of solvents and under various conditions, however.

Contractor: Louis Koenig - Research ($2360)

Project Director: Dr. Louis Koenig

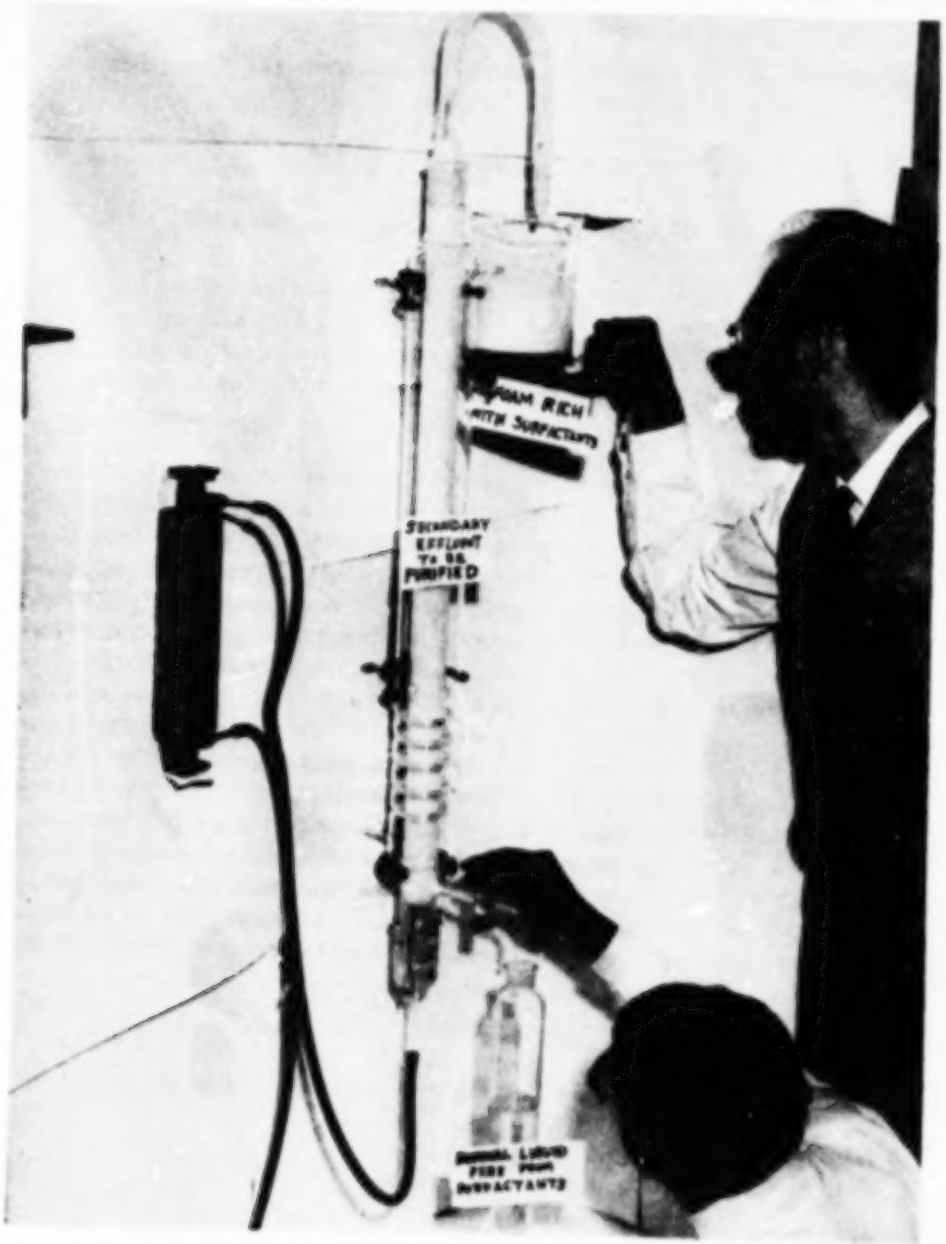
Period of Contract: November 1961

Purpose: Study ultimate disposal of advanced treatment wastes by injection to underground formations

Summary

The technical and economic feasibility of disposing of advanced treatment concentrates by injection into underground formations was evaluated.

Cost estimates were made for ultimate disposal of 1000, 100,000 and 2,000,000 gallons per day of hypothetical advanced treatment wastes at three concentrations. The well parameters



At the Esso Research and Engineering Company, Dr. R. M. Skomoroski (standing) and Dr. I. A. Eldib are experimenting with a foam fractionation apparatus. Under study are the characteristics of foaming columns, flow rates, reflux, and effect of additives in enhancing foaming.

were depth and a combination of reservoir pressure and formation transmissivity represented by 0, 260, and 900 psi well-head pressure exclusive of friction drop. A method was developed for synthesizing the costs of injection wells as a function of depth which reproduces the average cost of U. S. oil and gas wells at any depth. Economic diameters for the injection wells were computed for all values of the parameters. Capability was the strongest determi-

nant of conditioning and injecting costs. These are for average values of the other parameters, about $0.12 per 1000 gallons at 2,000,000 gpd, $4.50 per 1000 gallons at 100,000 gpd, and $27 per 1000 gallons 1000 gpd. The effects of well-head pressure exclusive of friction and of liquid density were neglibible at 1000 gpd but increased in importance at 2,000,000 gpd; contrastingly, the effect of depth was rather small at 2,000,000 gpd, but became the major determinant as capabilities decreased to 1000 gpd. Per thousand gallons, it is more expensive to inject a more dilute solution. The disposal cost per day is almost completely a function of the capability, and at constant capability is largely independent of the tons per day of contaminants fed, i.e., of the concentration. For an average case of 7000 foot well depth and 900 psi, the daily costs are approximately 27, 55, and 400 dollars per day for 1000, 100,000, and 2,000,000 gpd, respectively. Injection is much cheaper than wet oxidation as a means of ultimate disposal since, for the daily cost of disposing of 1000 and 100,000 gpd by wet oxidation, there could be disposed 10,000 and 2,000,000 gpd, respectively, by injection. The cost of disposal by injection, per thousand gallons of water produced by advanced waste treatment, is about 1.6 cents for 90 percent recovery of water and about 0.7 cents for 99 percent recovery.

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| Contractor: | Ionac Chemical Company ($20,253) |
| Project Director: | Mr. Allyn Hall |
| Period of Contract: | November 1961 - December 1962 |
| Purpose: | Conduct study to investigate the technical and economic feasibility of the sludge blanket adsorption process for the removal of refractory contaminants from waste waters |

Summary

It is the purpose of the Ionac contract to establish the feasibility of combining the clarifying ability of chemical coagulation and precipitation with the sorptive properties of inexpensive or reusable adsorbents and ion exchange materials in a sludge blanket filtration unit.

Various types of clays have sometimes been used in applying the sludge blanket filtration principle in order to improve the ability of the sludge to settle to a compact mass. Since these clays, as well as many other solids, possess certain adsorptive and ion exchange properties, they have potential for removing suspended and soluble contaminants from waste water. Some of these materials have already been used for the removal of soluble radioactive material and various ions.

Tests are planned on conventional water treatment coagulants, coagulant aids, and known, naturally occurring, commercially available adsorbents, or on waste materials with sorptive and/or ion exchange properties.

Ionac has completed a literature search and has submitted a literature summary and bibliography to outline their findings. The next phase of the project will be to screen a number of possible adsorbents, coagulants, and coagulant aids for use alone or in combination to remove refractory contaminants from waste waters.

Pictured here is foam that collected on the tanks of a secondary sewage treatment plant. Current practice is to knock the foam down by means of water sprays. Since the foaming materials are unwanted, advantage should be taken of the natural concentration that occurs in the foam and the foam should be disposed of separately. Deliberate and controlled foaming are under study as a useful mechanism for removing contaminants from waste waters.

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